

April 1, 2003

Memorandum

From: Matthew W. Spears  
Office of Transportation Air Quality

To: A-2001-28

Subject: "Changes Considered for Part 1065-Test Procedures and Equipment,"

There are several reasons EPA is considering changes for Part 1065-Test Procedures and Equipment:"

1. Regulated pollutant measurements at the nonroad Tier IV emissions standards, will require test procedures similar to those finalized for model year 2007 and later on-highway heavy-duty diesel engines.
2. This notice is proposing new transient nonroad certification test cycles that will require transient test procedures similar to those finalized for model year 2007 and later on-highway heavy-duty diesel engines.
3. EPA is migrating all engine test procedures and equipment specifications to Part 1065 in order to consolidate several similar sets of test procedures that were promulgated under separate rulemakings. This migration also facilitates rewriting these specifications in Plain Language as per Federal Register.
4. EPA is requesting comment on an alternative NTE concept for non-road diesel engines, and the associated test procedures for this alternative are published in this memorandum.

A complete text revision of Part 1065 is provided as Appendix A to this memorandum. It contains proposed changes in "redline/strikeout" while changes to which comment is requested is in "blueline/strikeout". Note that blueline/strikeout is only used in **Subpart J Field Testing**.

The following outline summarizes key changes to Part 1065, but the full-text document should be used as a more complete reference:

§ 1065.10

Inserted alternate test procedure approval provisions in 86.1306-2007.

§ 1065.105

Inserted dynamometer specifications in 89.306 for compression ignition engines.

§ 1065.115 Exhaust gas sampling system; compression ignition engines.

Inserted exhaust-gas sampling system specified in 40 CFR 86.1310, 86.1323, 86.1338 to measure emissions from compression-ignition nonroad engines.

§ 1065.125

Inserted analyzer accuracy, calibration frequency and leak check provisions in 89.305, 89.310, and 89.311 for compression ignition engines.

§ 1065.130

Inserted raw hydrocarbon analyzer specifications in 86.317-79 for compression ignition engines.

§ 1065.160 Particulate Mass Measurement Equipment

Inserted specifications in 86.1312-2007 for compression ignition engines.

§1065.205 Test fuel specifications for distillate diesel fuel.

For all emission tests, use test fuels meeting the specifications for diesel fuel in 40 CFR part 86 subpart N, except the minimum percent aromatics shall be 10%.

§ 1065.310 CVS calibration

Inserted specifications in 86.1319-90 and 86.1320-90 for compression ignition engines.

§ 1065.335 PM microbalance

Inserted specifications in 86.1312-2007 for compression ignition engines.

§ 1065.501 Overview

Inserted specifications in 86.1327-96, 86.1330-84, 86.1330-90, and 86.328 for compression ignition engines.

§ 1065.510 Engine Mapping Procedures

Inserted specifications in 86.1332-90 for compression ignition engines.

§ 1065.515 Test cycle generation

Inserted specifications in 86.1333-90 for compression ignition engines.

§ 1065.520 Engine starting restarting and shutdown

Inserted specifications in 86.1336-84 and 86.1335 for compression ignition engines.

§ 1065.525

Inserted specifications in 86.1337-2007 for compression ignition engines.

§ 1065.30 Cycle statistics

Inserted specifications in 86.1341-98 for compression ignition engines.

§ 1065.535 PM test procedures

Inserted specifications in 86.1312-2007 for compression ignition engines.

§ 1065.610 Bag sample analysis

Inserted specifications in 86.1338-84, 86.1340-94-2007 for compression ignition engines.

§ 1065.615 Bag sample calculations

Inserted specifications in 86.344-79, 86.1342-94, 86.1343-88, and 89.331 for compression ignition engines.

§ 1065.620 Continuous sample calculations

Inserted specifications in 89.331, 89.417, 89.418 for compression ignition engines.

§ 1065.701 Particulate measurements.

Inserted particulate sampling system and procedures specified in 40 CFR part 86 subpart N to measure particulate emissions from compression-ignition nonroad engines.

Changes to which comments are requested are not included in this summary. These full text changes can be found in Subpart J of Appendix A, and these are presented in blueline/strikeout.

Respectfully Submitted,

Matthew William Spears

## **Appendix A: PART 1065—TEST PROCEDURES AND EQUIPMENT**

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- 1065.110 Exhaust gas sampling system; spark-ignition (SI) engines.
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**Subpart K—Definitions and Other Reference Information**

1065.1001 Definitions.  
1065.1005 Symbols, acronyms, and abbreviations.  
1065.1010 Reference materials.  
1065.1015 Confidential information.

**Authority:** 42 U.S.C. 7401–7671(q).

**Subpart A—Applicability and General Provisions**

**§ 1065.1 Applicability.**

(a) This part describes the procedures that apply to testing that we require for the following engines or for equipment using the following engines:

- (1) Large nonroad spark-ignition engines we regulate under 40 CFR part 1048.
- (2) Vehicles that we regulate under 40 CFR part 1051 (*i.e.*, recreational SI vehicles) that are regulated based on engine testing. See 40 CFR part 1051 to determine which vehicles may be certified based on engine test data.

(b) This part does not apply to any of the following engine or vehicle categories:

- (1) Light-duty highway vehicles (see 40 CFR part 86).
- (2) Heavy-duty highway Otto-cycle engines (see 40 CFR part 86).
- (3) Heavy-duty highway diesel engines (see 40 CFR part 86).
- (4) Aircraft engines (see 40 CFR part 87).
- (5) Locomotive engines (see 40 CFR part 92).
- (6) Land-based nonroad diesel engines (see 40 CFR part 89).
- (7) General marine engines (see 40 CFR parts 89 and 94).
- (8) Marine outboard and personal watercraft engines (see 40 CFR part 91).
- (9) Small nonroad spark-ignition engines (see 40 CFR part 90).

(c) This part is addressed to you as a manufacturer, but it applies equally to anyone who does testing for you, and to us when we conduct testing to determine if you meet emission standards.

(d) Paragraph (a) of this section identifies the parts of the CFR that define emission standards and other requirements for particular types of engines. In this part 1065, we refer to each of these other parts

generically as the “standard-setting part.” For example, 40 CFR part 1051 is always the standard-setting part for snowmobiles. Follow the standard-setting part if it differs from this part.

(e) For equipment subject to this part and regulated under equipment-based or vehicle-based standards, interpret the term “engine” in this part to include equipment and vehicles(see 40 CFR 1068.30).

#### § 1065.5 Overview of test procedures.

(a) Some of the provisions of this part do not apply to all types of engines. For example, measurement of particulate matter is generally not required for spark-ignition engines. See the standard-setting part to determine which provisions in this part may not apply. Before using this part’s procedures, read the standard-setting part to answer at least the following questions:

- (1) How should I warm up the test engine before measuring emissions? Do I need to measure cold-start emissions during this warm-up segment of the duty cycle?
  - (2) Do I measure emissions while the warmed-up engine operates over a steady-state schedule, a transient schedule, or both?
  - (3) What are the speed and load points of the test cycle(s)?
  - (4) Which exhaust constituents do I need to measure?
  - (5) Does testing require full-flow dilute sampling? Is raw sampling acceptable? Is partial-flow dilute sampling acceptable?
  - (6) Do any unique specifications apply for test fuels?
  - (7) What maintenance steps may I do before or between tests on an emission data engine?
  - (8) Do any unique requirements apply to stabilizing emission levels on a new engine?
  - (9) Do any unique requirements apply to testing conditions, such as ambient temperatures or pressures?
  - (10) Are there special emission standards that affect engine operation and ambient conditions?
  - (11) Are there different emission standards that apply to field testing under normal operation?
- (b) The following table shows how this part divides testing specifications into subparts:

This subpart...	Describes these specifications or procedures...
Subpart A .....	General provisions for test procedures.
Subpart B .....	Equipment for testing.
Subpart C .....	Fuels and analytical gases for testing.
This subpart...	Describes these specifications or procedures...
Subpart D .....	How to calibrate test equipment.
Subpart E .....	How to prepare engines for testing, including service accumulation.
Subpart F .....	How to test for emissions.
Subpart G .....	How to calculate emission levels from measured data.
Subpart H .....	[Reserved].
Subpart I .....	How to measure emissions from engines fueled with an oxygenated fuel such as methanol or ethanol.
Subpart J .....	How to do field testing of in-use vehicles and equipment.
Subpart K .....	Definitions, abbreviations, and other reference information that apply to emission testing.

#### **§ 1065.10 Other test procedures.**

(a) *Your testing.* These test procedures apply for all testing that you do to show compliance with emission standards, with a few exceptions listed in this section.

(b) *Our testing.* These test procedures generally apply for testing that we do to determine if your engines comply with applicable emission standards. We may conduct other testing as allowed by the Act.

(c) *Exceptions.* You may be allowed or required to use test procedures other than those specified in this part in the following cases:

(1) The test procedures in this part are intended to produce emission measurements equivalent to those that would result from measuring emissions during in-use operation using the same engine configuration installed in a piece of equipment. If good engineering judgment indicates that use of the procedures in this part for an engine would result in measurements that are not representative of in-use operation of that engine, you must notify us. If we determine that using these procedures would result in measurements that are significantly unrepresentative and that changing the procedures will result in more representative measurements and not decrease the stringency of emission standards, we will specify changes to the procedures. In your notification to us, you should recommend specific changes you think are necessary.

(2) You may ask to use emission data collected using other test procedures, such as those of the California Air Resources Board or the International Organization for Standardization. We will allow this only if you show us that these data are equivalent to data collected using our test procedures.

(3) You may ask to use alternate procedures that produce measurements equivalent to those from the specified procedures. If you send us a written request showing your procedures are equivalent, and we agree that they are equivalent, we will allow you to use them. You may not use an alternate procedure until we approve them, either by: telling you directly that you may use this procedure; or issuing guidance to all manufacturers, which allows you to use the alternate procedure without additional approval. You may utilize this provision under the following conditions.

(c)(1) Upon request, the Administrator may allow a manufacturer to use some of the test equipment and procedures allowed for model years prior to the effective date of a given standard instead of the test equipment and procedures required for that model year and later engines, provided that good engineering judgment indicates that it would not adversely affect determination of compliance with the applicable emission standards of this part.

(2) A manufacturer may use the test equipment and procedures required for later model year engines for testing of earlier model year engines.(d) Approval of alternate test system. (1) If on the basis of the information described in paragraph (d) (5) of this section, the Administrator determines that an alternate test system would consistently and reliably produce emission test results that are at least equivalent to the results produced using the test systems described in this subpart, he/she shall approve the alternate system for optional use instead of the test systems described in this subpart. This provision is applicable to any test system used for determining compliance with the applicable standard for any model year engine.

(2) Any person may submit an application for approval of an alternate test system. Anyone who intends to submit an application is encouraged to first contact EPA Office of Transportation and Air Quality, Assessment and Standards Division. The Division may provide further guidance specific to the respective test system.

(3) In approving an alternate test system, the Administrator may approve it for general use, or may approve it conditionally.

(4) The Administrator may revoke the approval on the basis of new information that indicates that the alternate test system is not equivalent. However, revocation of approval must allow manufacturers sufficient lead-time to change the test system to an approved system. In determining the amount of lead-time that is required, the Administrator will consider relevant factors such as:

(i) The ease with which the test system can be converted to an approved system.

(ii) The degree to which the alternate system affects the measured emission rates.

(iii) Any relevant conditions included in the approval.

(5) The application for approval must include:

(i) An explanation of the theoretical basis of the alternate system. This technical description should explain why the detection principle of the alternate system would provide equivalent results to the detection principle of the prescribed system for the full range of emission properties being measured. This description may include equations, figures, and references. For example, a NO<sub>x</sub> measurement application

should theoretically relate the alternate detection principle to the prescribed detection principle of detecting nitric oxide for a typical range of NO to NO<sub>2</sub> ratios. A PM mass measurement application should explain the principle(s) by which the alternate system quantifies PM mass independent of PM composition, and how it is impacted by semi-volatile and volatile species= phase distributions. For any proportioning or integrating system such as a partial flow diluter or a bag mini-diluter, the application should compare the alternate system's theoretical response to the prescribed system's response.

(ii) A technical description of the alternate system. This section shall detail all of the hardware and software included in the alternate system. Dimensioned drawings, flow-charts, schematics, and component specifications shall be included. Any data manipulation (i.e. calculations) that the system performs shall be presented in this section.

(iii) A description of the procedures used to operate the system including the level of training that an operator must have to achieve acceptable results. This section of the application shall describe all of the installation, calibration, operation, and maintenance procedures in a step-by-step format. Note that empirical calibration with respect to another prescribed or approved measurement system is not acceptable. Calibration should be performed with NIST traceable standards, or equivalent national standards. Other standards may be approved in advance by the Administrator. Diagrams, schematics, and other graphics may be used to enhance the description.

(iv) A comparison of results from the alternate system and from the prescribed system or other system approved by the Administrator. The two systems must be calibrated independently to NIST traceable standards or equivalent national standards for this comparison. Other standards may be approved in advance by the Administrator. While other statistical analyses may be acceptable, it is recommended that the comparison be based on a minimum of 7 collocated and simultaneous tests. This comparison shall be performed over the applicable transient test cycle using an engine that is fully warmed up such that its coolant temperature is thermostatically controlled. If there is no applicable transient test cycle, the applicable steady-state cycle may be used. Anyone who intends to submit an application is encouraged to first contact EPA Office of Transportation and Air Quality, Assessment and Standards Division to discuss the applicant's intended statistical analysis. The Division may provide further guidance specific to the appropriate statistical analysis for the respective application. While other statistical analyses may be used, the following statistical tests are suggested. If the comparison is paired, it must demonstrate that the alternate system passes a two-sided, paired t-test described in this paragraph. If the test is unpaired, it must demonstrate that the alternate system passes a two-sided, unpaired t-test described in this paragraph. Other statistical criteria may be set by the Administrator. The average of these tests for the reference system must return results less than or equal to the applicable emissions standard. The t-test is performed as follows, where "n" equals the number of tests:

(A) Calculate the average of the alternate system results; this is  $A_{avg}$ .

(B) Calculate the average of the results of the system to which the alternate system was referenced; this is  $R_{avg}$ .

(C) , Calculate the "n-1" standard deviations for the alternate and reference averages; these are  $A_{sd}$  and  $R_{sd}$  respectively. . Form the F ratio:  $F = (A_{sd}/R_{sd})^2$ . F must be less than the critical t value,  $F_{crit}$  at a 90% confidence interval for "n-1" degrees of freedom. The following table lists 90% confidence interval  $F_{crit}$  values for n-1 degrees of freedom. Note that  $n_A$  represents the number of alternate system samples, while  $n_R$  represents the number of reference system samples.

	$n_A-1$	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
$n_R-1$																
6		3.055	3.014	2.983	2.958	2.937	2.92	2.905	2.892	2.881	2.871	2.863	2.855	2.848	2.842	2.836
7		2.827	2.785	2.752	2.725	2.703	2.684	2.668	2.654	2.643	2.632	2.623	2.615	2.607	2.601	2.595
8		2.668	2.624	2.589	2.561	2.538	2.519	2.502	2.488	2.475	2.464	2.455	2.446	2.438	2.431	2.425
9		2.551	2.505	2.469	2.44	2.416	2.396	2.379	2.364	2.351	2.34	2.329	2.32	2.312	2.305	2.298
10		2.461	2.414	2.377	2.347	2.323	2.302	2.284	2.269	2.255	2.244	2.233	2.224	2.215	2.208	2.201
11		2.389	2.342	2.304	2.274	2.248	2.227	2.209	2.193	2.179	2.167	2.156	2.147	2.138	2.13	2.123
12		2.331	2.283	2.245	2.214	2.188	2.166	2.147	2.131	2.117	2.105	2.094	2.084	2.075	2.067	2.06
13		2.283	2.234	2.195	2.164	2.138	2.116	2.097	2.08	2.066	2.053	2.042	2.032	2.023	2.014	2.007
14		2.243	2.193	2.154	2.122	2.095	2.073	2.054	2.037	2.022	2.01	1.998	1.988	1.978	1.97	1.962
15		2.208	2.158	2.119	2.086	2.059	2.037	2.017	2	1.985	1.972	1.961	1.95	1.941	1.932	1.924
16		2.178	2.128	2.088	2.055	2.028	2.005	1.985	1.968	1.953	1.94	1.928	1.917	1.908	1.899	1.891
17		2.152	2.102	2.061	2.028	2.001	1.978	1.958	1.94	1.925	1.912	1.9	1.889	1.879	1.87	1.862

18		2.13	2.079	2.038	2.005	1.977	1.954	1.933	1.916	1.9	1.887	1.875	1.864	1.854	1.845	1.837
19		2.109	2.058	2.017	1.984	1.956	1.932	1.912	1.894	1.878	1.865	1.852	1.841	1.831	1.822	1.814
20		2.091	2.04	1.999	1.965	1.937	1.913	1.892	1.875	1.859	1.845	1.833	1.821	1.811	1.802	1.794

(D) For an unpaired comparison, calculate the t-value:

$$t_{\text{unpaired}} = (A_{\text{avg}} - R_{\text{avg}}) / ((A_{\text{sd}}^2 + R_{\text{sd}}^2) / n)^{1/2}$$

(E) For a paired comparison, calculate the “n-1” standard deviation (squared) of the differences,  $d_i$ , between the paired results, where “i” represents the  $i^{\text{th}}$  test of n number of tests:

$$S_D^2 = (\sum d_i^2 - ((\sum d_i)^2 / n)) / (n-1)$$

(F) For a paired comparison, calculate the t-value:

$$t_{\text{paired}} = (A_{\text{avg}} - R_{\text{avg}}) / (S_D^2 / n)^{1/2}$$

(2) The absolute value of t must be less than the critical t value,  $t_{\text{crit}}$ , at a 90% confidence interval for “n-1” degrees of freedom. The following table lists 90% confidence interval  $t_{\text{crit}}$  values for n-1 degrees of freedom:

90% Confidence interval critical t values vs. n-1 degrees of freedom for a two-sided, paired t-test	
n-1	$t_{\text{crit}}$
6	1.94
7	1.89
8	1.86
9	1.83
10	1.81
11	1.80
12	1.78
13	1.77
14	1.76
15	1.75
16	1.75
17	1.74
18	1.73
19	1.73
20	1.72

(4) You may ask to use special test procedures if your engine cannot be tested under the specified procedures (for example, your engine cannot operate on the specified transient cycle). In this case, tell us in writing why you cannot satisfactorily test your engines using this part’s procedures and ask to use a different approach. We will approve your special test procedures if we determine they would produce emission measurements that are representative of those that would result from measuring emissions during in-use operation. You may not use special procedures until we approve them.

(5) The standard-setting part may contain other specifications for test procedures that apply for your engines. In cases where it is not possible to comply with both the test procedures in those parts and the test procedures in this part, you must comply with the test procedures specified in the standard setting part. Those other parts may also allow you to deviate from the test procedures of this part for other reasons.

#### § 1065.15 Engine testing.

(a) This part describes the procedures for performing exhaust emission tests on engines that must meet emission standards.

(b) Generally, you must test an engine while operating it on a laboratory dynamometer over a prescribed sequence. (Subpart J of this part describes in-use testing of engines installed in vehicles or equipment.) You need to sample and analyze the exhaust gases generated during engine operation to determine the concentration of the regulated pollutants.

(c) Concentrations are converted into units of grams of pollutant per kilowatt hour (g/kW-hr) or similar units for comparison to emission standards. If the applicable emission standards are expressed as g/bhp-hr, references in this part to kW should generally be interpreted to mean horsepower.

**§ 1065.20 Limits for test conditions.**

- (a) Unless specified elsewhere in this chapter, you may conduct tests to determine compliance with duty-cycle emission standards at ambient temperatures of 20–30°C (68–86°F), ambient pressures of 600–775 mm Hg, and any ambient humidity level.
- (b) Follow the standard-setting part for ambient conditions when testing to determine compliance with not-to-exceed or other off-cycle emission standards.
- (c) For engine testing in a laboratory, you may heat, cool, and/or dehumidify the dilution air before it enters the CVS.
- (d) For engine testing in a laboratory, if the barometric pressure observed while generating the maximum-torque curve changes by more than 25 mm Hg from the value measured when you started mapping, you must remap the engine. Also, to have a valid test, the average barometric pressure observed during the exhaust emission test must be within 25 mm Hg of the average observed during the maximum torque curve generation (see § 1065.510).

**Subpart B—Equipment and Analyzers**

**§ 1065.101 Overview.**

This subpart describes equipment and analyzers for measuring emissions. Subpart D of this part describes how to calibrate these devices and subpart C of this part defines the accuracy and purity specifications of analytical gases.

**§ 1065.105 Dynamometer and engine equipment specifications.**

- (a) The engine dynamometer system must be able to control engine torque and speed simultaneously over the applicable test cycles within the accuracies specified in § 1065.530. If your dynamometer cannot meet the accuracy requirements in § 1065.530, you must get our approval before using it. For transient testing, issue command set points for engine torque and speed at 5 Hz or greater (10 Hz recommended). Record feedback engine torque and speed at least once every second during the test. In addition to these general requirements, make sure your engine or dynamometer's readout signals for speed and torque meet the following accuracies for all testing:
  - (1) Engine speed readout must be accurate to within  $\pm 2$  percent of the absolute standard value. A 60-tooth (or greater) wheel in combination with a common mode rejection frequency counter is considered an absolute standard for engine or dynamometer speed.
  - (2) Engine flywheel torque readout must meet one of the two following standards for accuracy:
    - (i) Within 3 percent of the NIST true value torque (as defined in § 1065.315).
    - (ii) The following accuracies:

If the full-scale torque value is...	Engine flywheel torque readout must be within...
$T \leq 550$ ft-lbs. ....	$\pm 2.5$ ft-lbs. of NIST true value.
$550 < T \leq 1050$ ft-lbs.	$\pm 5.0$ ft-lbs. of NIST true value.
$T > 1050$ ft-lbs.	$\pm 10.0$ ft-lbs. of NIST true value.

(3) Option: You may use internal dynamometer signals (such as armature current) to measure torque if you can show that the engine flywheel torque during the test cycle conforms to paragraph (b)(2) of this section. Your measurements must compensate for increased or decreased flywheel torque because of the armature's inertia during accelerations and decelerations in the test cycle.

(b) To verify that the test engine has followed the test cycle correctly, collect the dynamometer or engine readout signals for speed and torque so you can statistically correlate the engine's actual performance with the test cycle (see § 1065.530). Normally, to do this, you would convert analog signals from the dynamometer or engine into digital values for computer storage, but all conversions must meet two criteria:

(1) Speed values used to evaluate cycles must be accurate to within 2 percent of the readout value for dynamometer or engine speed.

(2) Engine flywheel torque values used to evaluate cycles must be accurate to within 2 percent of the readout value for dynamometer or engine flywheel torque.

(c) You may combine the tolerances in paragraphs (a) and (b) of this section if you use the root mean square (RMS) method and refer accuracies of the RMS values to absolute-standard or NIST true values.

(1) Speed values used to evaluate cycles must be accurate to within 2.8 percent of the absolute standard values, as defined in paragraph (a)(1) of this section.

(2) Engine flywheel torque values used to evaluate cycles must be accurate to within  $\pm 3.6$  percent of NIST true values, as determined in § 1065.315.

## General

When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dynamometer shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.

## Eddy-current dynamometer

If the engine is tested with an eddy-current dynamometer, it is recommended that the number of points, where the difference  $T_{sp} - 2 \cdot \pi \cdot \dot{n}_{sp} \cdot \Theta_D$  is smaller than - 5% of the peak torque, does not exceed 30.

where  $T_{sp}$  is the demanded torque,  $\dot{n}_{sp}$  is the derivative of the engine speed and  $\Theta_D$  is the rotational inertia of the eddy-current dynamometer.

## Specific test conditions

### Engine air inlet system

An engine air intake system shall be used presenting an air intake restriction within  $\pm 300$  Pa of the value specified

by the engine manufacturer for a clean air cleaner and in accordance with the respective regulation.

If the engine is equipped with an integral air inlet system, it shall be used for testing.

### Engine exhaust system

A vehicle exhaust system or a test shop system shall be used presenting an exhaust backpressure within  $\pm 650$  Pa

of the value specified by the engine manufacturer and in accordance with the respective regulation. The exhaust

system shall conform to the requirements for exhaust gas sampling, as set out in 7.5.4, 16.2.1, EP and 16.2.2, EP.

If the engine is equipped with an integral exhaust system, it shall be used for testing.

#### Cooling system

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer shall be used.

#### Lubricating oil

Specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

#### Fuel Oil

The fuel temperature shall be in accordance with the manufacturer's recommendations. The fuel temperature shall

be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded.

#### Accuracy

The calibration of all measuring instruments shall be traceable to national (international) standards and comply with the requirements given in tables 2 and 3.

NOTE Calibration requirements for analyzers are given in a).

The instruments shall be calibrated as required by internal audit procedures, by the instrument manufacturer or in

accordance with ISO 9000 requirements. The deviations given in table 2 and table 3 refer to the final recorded

value, which is inclusive the data acquisition system.

#### Table 2 — Permissible deviations of instruments for engine related parameters

No. Measurement instrument Permissible deviation

1 Engine speed  $\pm 2$  % of reading or  $\pm 1$  % of engine's max value whichever is larger

2 Torque  $\pm 2$  % of reading or  $\pm 1$  % of engine's max value whichever is larger

3 Fuel consumption  $\pm 2$  % of engine's max value

4 Air consumption  $\pm 2$  % of reading or  $\pm 1$  % of engine's max value whichever is larger

5 Exhaust gas flow  $\pm 2,5$  % of reading or  $\pm 1,5$  % of engine max. value whichever is larger

a The calculations of the exhaust emissions as described in this part of ISO 8178 are, in some cases, based on

different measurement and/or calculation methods. Because of limited total tolerances for the exhaust emission

calculation, the allowable values for some items, used in the appropriate equations, must be smaller than the allowed

tolerances given in ISO 3046-3.

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#### Table 3 — Permissible deviations of instruments for other essential parameters

No. Measurement instrument Permissible deviation

1 Temperatures  $\delta 600$  K  $\pm 2$  K absolute

2 Temperatures  $> 600$  K  $\pm 1$  % of reading

3 Exhaust gas pressure  $\pm 0,2$  kPa absolute

4 Intake air depressions  $\pm 0,05$  kPa absolute

5 Atmospheric pressure  $\pm 0,1$  kPa absolute

6 Other pressures  $\pm 0,1$  kPa absolute

7 Relative humidity  $\pm 3$  % absolute

8 Absolute humidity  $\pm 5$  % of reading

9 Dilution air flow  $\pm 2$  % of reading

10 Diluted exhaust gas flow  $\pm 2$  % of reading

### Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of rated power and full load, within  $\pm 5$  K of the maximum charge air temperature specified by the manufacturer. The temperature of the cooling medium shall be at least 293 K (20°C).

If a test shop system or external blower is used, the charge air temperature shall be set to within  $\pm 5$  K of the maximum charge air temperature specified by the manufacturer at the speed of the declared maximum power and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall not be changed for the whole test cycle. The charge air cooler volume shall be based upon good engineering practice and typical vehicle/machinery applications.

Optionally, the setting of the charge air cooler may be done in accordance with SAE J 1937.

### Cooling system

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer shall be used.

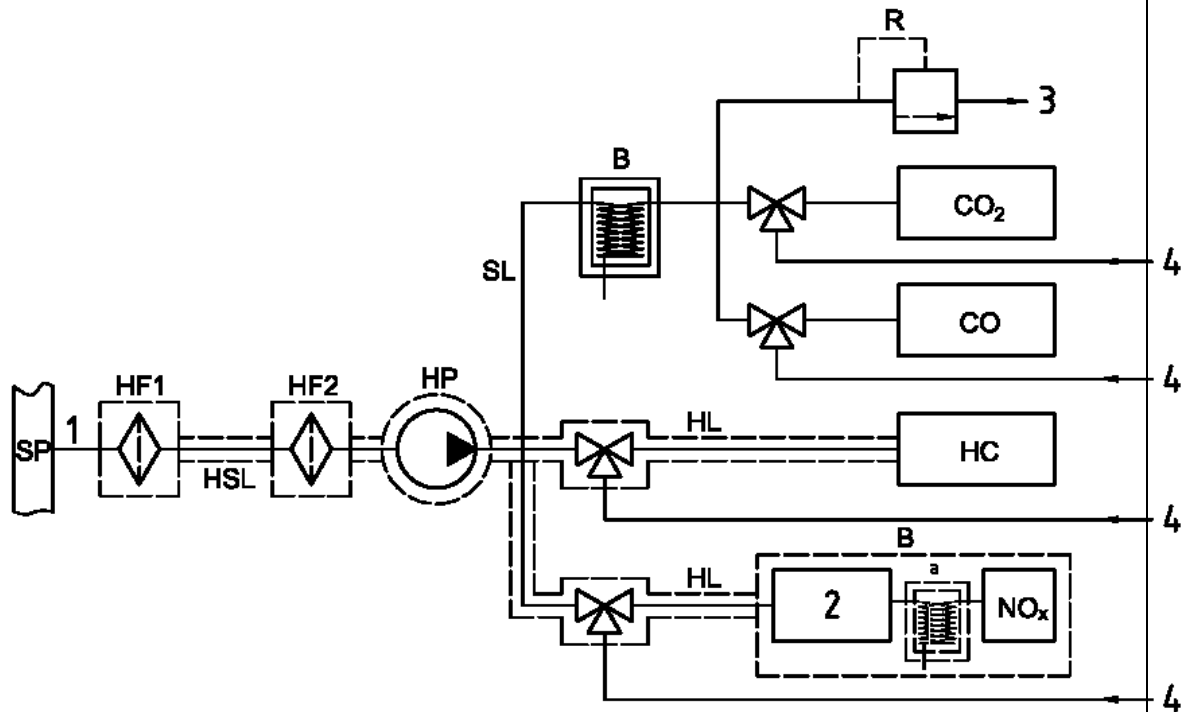


Figure 3 — Flow diagram of raw exhaust gas analysis system for CO, CO<sub>2</sub>, NO<sub>x</sub>, HC and O<sub>2</sub>

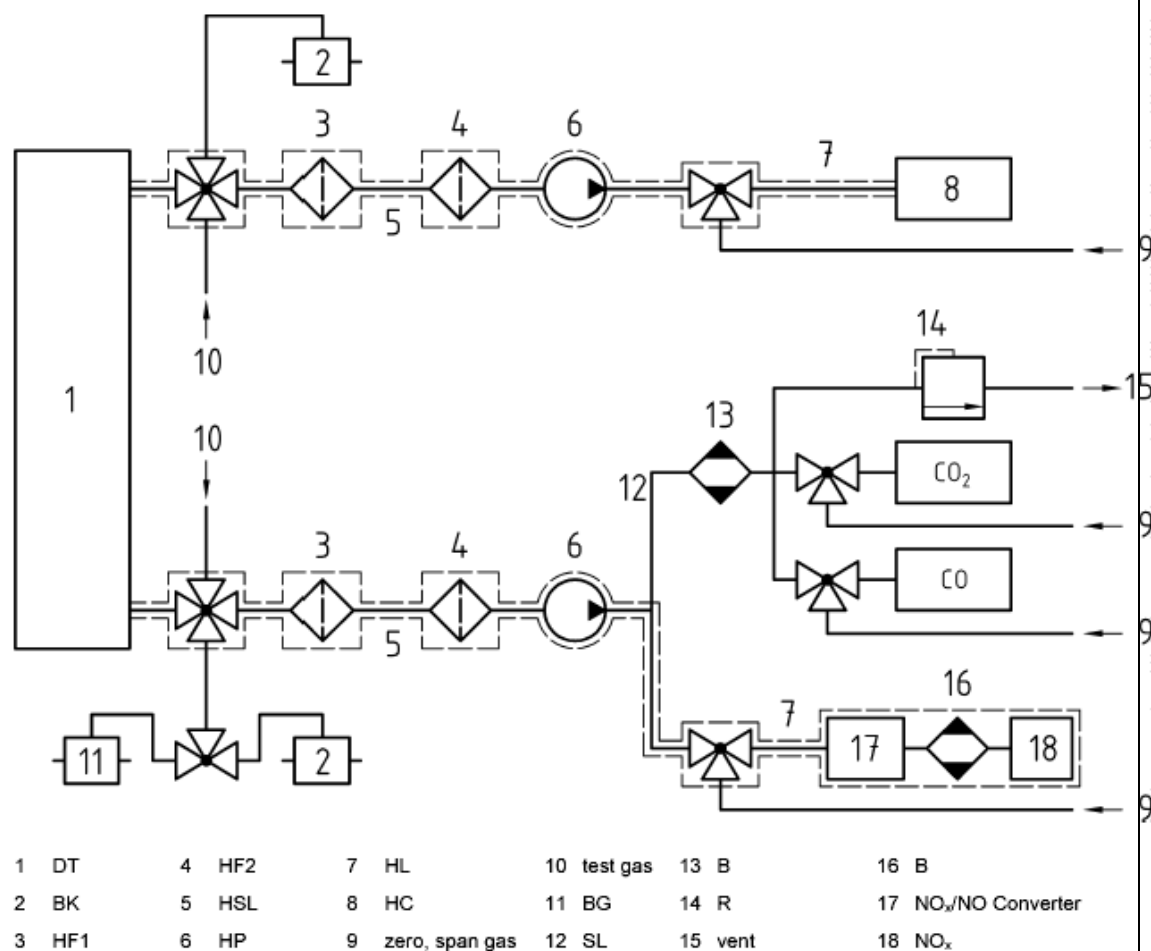


Figure 4 — Flow diagram of diluted exhaust gas analysis system for CO, CO<sub>2</sub>, NO<sub>x</sub>, HC and O<sub>2</sub>

### Components of figures 2 and 3

#### General

All components in the sampling gas path must be maintained at the temperatures specified for the respective systems.

#### SP1 — raw exhaust gas sampling probe (figure 2 only)

NOTE If exhaust pulsations or engine vibrations are likely to change the sampling probe, the wall thickness of the probe may be enlarged with the agreement of the parties involved.

#### SP2 — dilute exhaust gas HC sampling probe (figure 3 only)

#### SP3 — dilute exhaust gas CO, CO<sub>2</sub>, NO<sub>x</sub> sampling probe (figure 3 only)

The probe shall:

- . be in the same plane as SP2;
- . be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- . be heated and insulated over its entire length to a minimum temperature of 328 K (55 °C) to prevent water condensation.

#### HSL1 — heated sampling line

The sampling line provides a gas sample from a single probe to the split point(s) and the HC analyser.

The sampling line shall:

. be made of stainless steel or PTFE.

a) For non-methanol-fuelled engines

If the temperature of the exhaust gas at the sampling probe is equal to or below 463 K (190 °C), maintain a wall

temperature of 463 K  $\pm$  10 K (190 °C  $\pm$  10 °C) as measured at every separately controlled heated section.

If the temperature of the exhaust gas at the sampling probe is above 463 K (190 °C), maintain a wall temperature

greater than 453 K (180 °C).

Immediately before the heated filter F2 and the HFID, maintain a gas temperature of 463 K  $\pm$  10 K (190 °C  $\pm$  10°C).

### **HSL2 — heated NO<sub>x</sub> (and NH<sub>3</sub>) sampling line**

The sampling line shall:

. maintain a wall temperature of 328 K to 473 K (55 °C to 200 °C), up to the converter C when using a cooling bath B, and up to the analyser when a cooling bath B is not used;

. be made of stainless steel or PTFE.

NOTE Since the sampling line need only be heated to prevent condensation of water and sulfuric acid, the sampling line

temperature will depend on the sulfur content of the fuel.

### **SL — sampling line for CO, (CO<sub>2</sub>, O<sub>2</sub>)**

The line shall be made of PTFE or stainless steel. It may be heated or unheated.

### **BK — background bag (optional; figure3 only)**

For the measurement of the background concentrations.

### **BG — sample bag (optional; figure3 CO and CO<sub>2</sub> only)**

For the measurement of the sample concentrations.

### **F1 — heated pre-filter (optional)**

The temperature shall be the same as HSL1.

### **F2 — heated filter**

The filter shall extract any solid particles from the gas sample before the analyser. The temperature shall be the

same as HSL1. The filter shall be changed as needed.

### **P — heated sampling pump**

The pump shall be heated to the temperature of HSL1.

### **HC**

Heated flame ionization detector (HFID) for the determination of the hydrocarbons. The temperature shall be kept

at 453 K to 473 K (180 °C to 200 °C)

### **CO, CO<sub>2</sub>**

NDIRs for the determination of carbon monoxide and carbon dioxide.

### **NO**

CLD or HCLD for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of 328 K to 473 K (55 °C to 200 °C).

### **C — converter**

A converter shall be used for the catalytic reduction of NO<sub>2</sub> to NO prior to analysis in the CLD or HCLD.

### **O<sub>2</sub>**

PMD, ZRDO or ECS for the determination of oxygen.

### **B — cooling bath (optional)**

The bath shall be maintained at a temperature of 273 K to 277 K (0 °C to 4 °C) by ice or refrigerator. It is optional if the analyser is free from water vapour interference as determined in 8.9.2 and 8.9.3. If water is removed by condensation, the sample gas temperature or dew point shall

be monitored either within the water trap or downstream. The sample gas temperature or dew point shall not exceed 280 K (7 °C). Chemical dryers are not allowed for removing water from the sample.

**Response time:** Difference in time between a rapid change of the component to be measured at the reference point and the appropriate change in the response of the measuring system whereby the change of the measured component is at least 60% FS and takes place in less than 0.1 second

**NOTE 2** The system response time ( $t_{90}$ ) consists of the delay time to the system and of the rise time of the system.

**NOTE 3** The response time may vary dependent on where the reference point for the change of the component to be measured is defined, either at the sampling probe or directly at the port entrance of the analyzer; in this International Standard, the sampling probe is defined as the reference point.

**Delay time:** Time between the change of the component to be measured at the reference point and a system response of 10% of the final reading ( $t_{10}$ )

**NOTE 4** For the gaseous components, this is basically the transport time of the measured component from the sampling probe to the detector.

**NOTE 5** See NOTE 3. For the delay time, the sampling probe is defined as the reference point.

**Rise time:** Time between the 10% and 90% response of the final reading ( $t_{90} - t_{10}$ )

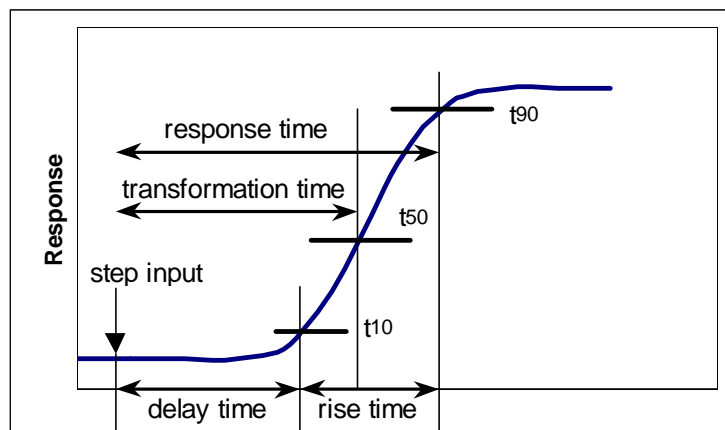
**NOTE 6** This is the instrument response after the component to be measured has reached the instrument.

**NOTE 7** See NOTE 3. For the rise time, the sampling probe is defined as the reference point.

**Transformation time:** Time between the change of the component to be measured at the reference point and a system response of 50% of the final reading ( $t_{50}$ )

**NOTE 8** See NOTE 3. For the transformation time, the sampling probe is defined as the reference point.

**NOTE 9** The transformation time is used for the signal alignment of different measurement instruments.



## **Figure 1 — Definitions of system response**

### **§ 1065.110 Exhaust gas sampling system; spark-ignition (SI) engines.**

(a) *General.* The exhaust gas sampling system described in this section is designed to measure the true mass of gaseous emissions in the exhaust of SI engines. (If the standard-setting part requires determination of THCE or NMHCE for your engine, then see subpart I of this part for additional requirements.) Under the constant volume sampler (CVS) concept, you must measure the total volume of the mixture of exhaust and dilution air and collect a continuously proportioned volume of sample for analysis. You must control flow rates so that the ratio of sample flow to CVS flow remains constant. You then determine the mass emissions from the sample concentration and total flow over the test period.

(1) Do not let the CVS or dilution air inlet system artificially lower exhaust system backpressure. To verify proper backpressures, measure pressure in the raw exhaust immediately upstream of the inlet to the CVS. Continuously measure and compare the static pressure of the raw exhaust observed during a transient cycle—with and without the CVS operating. Static pressure measured with the CVS system operating must remain within  $\pm 5$  inches of water (1.2

kPa) of the static pressure measured when disconnected from the CVS, at identical moments in the test cycle.

(Note: We will use sampling systems that can maintain the static pressure to within  $\pm 1$  inch of water (0.25 kPa) if your written request shows that this closer tolerance is necessary.) This requirement serves as a design specification for the CVS/dilution air inlet system, and should be performed as often as good engineering practice dictates (for example, after installing an uncharacterized CVS, adding an unknown inlet restriction on the dilution air, or otherwise altering the system).

(2) The system for measuring temperature (sensors and readout) must have an accuracy and precision of  $\pm 3.4^\circ$

F ( $\pm 1.9^\circ$ C). The temperature measuring system for a CVS without a heat exchanger must respond within 1.50 seconds to 62.5 percent of a temperature change (as measured in hot silicone oil). For a CVS with a heat exchanger, there is no specific requirement for response time.

(3) The system for measuring pressure (sensors and readout) must have an accuracy and precision of  $\pm 3$  mm Hg (0.4 kPa).

(4) The flow capacity of the CVS must be large enough to keep water from condensing in the system. You may dehumidify the dilution air before it enters the CVS. You also may heat or cool the air if three conditions exist:

(i) The air (or air plus exhaust gas) temperature does not exceed 250°F (121°C).

(ii) You calculate the CVS flow rate necessary to prevent water condensation based on the lowest temperature in the CVS before sampling. (We recommend insulating the CVS system when you use heated dilution air.)

(iii) The dilution ratio is high enough to prevent condensation in bag samples as they cool to room temperature.

(5) Bags for collecting dilution air and exhaust samples must be big enough for samples to flow freely.

(6) The general CVS sample system consists of a dilution air filter (optional) and mixing assembly, cyclone particulate separator (optional), a sample line for the bag sample or other sample lines a dilution tunnel, and associated valves and sensors for pressure and temperature. Except for the system to sample hydrocarbons from two-stroke engines, the temperature of the sample lines must be more than 3°C above the mixture's maximum dew point and less than 121°C. We recommend maintaining them at  $113 \pm 8^\circ$ C. For the hydrocarbon sampling system with two-stroke engines, the temperature of the sample lines should be maintained at  $191 \pm 11^\circ$ C. A general schematic of the SI sampling system is shown in Figure 1065.110–1, which follows:

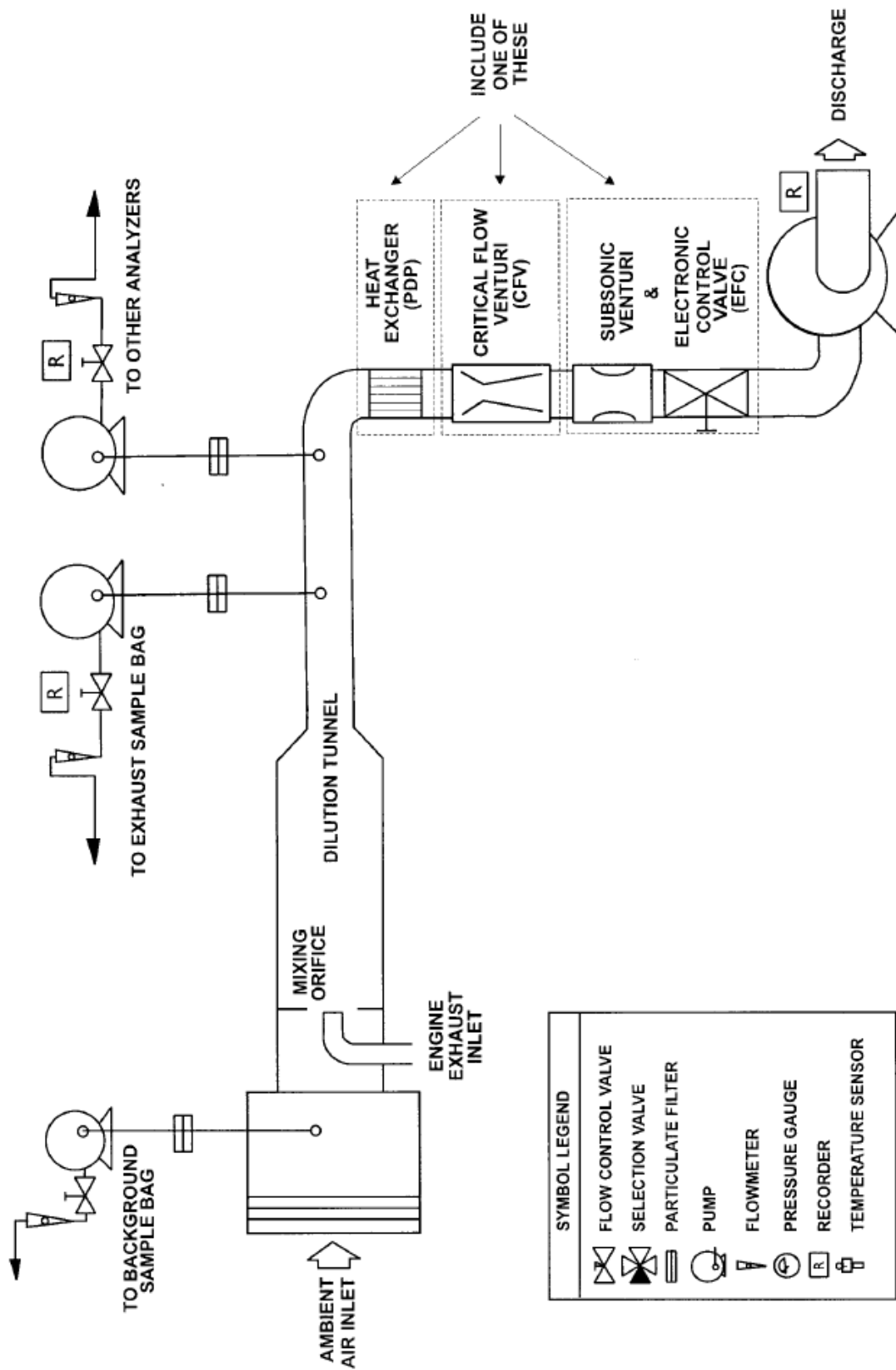


FIGURE 1065.110-1

## GENERIC GASEOUS EMISSIONS SAMPLING SYSTEM

(b) *Steady-state testing.* Constant proportional sampling is required throughout transient testing, but is not required throughout steady-state testing. Steady-state testing requires that you draw a proportional sample

for each test mode, but you may sample in different proportions for different test modes, as long as you know the ratio of the sample flow to total flow during each test mode. This allowance means that you may use simpler flow control systems for steady state testing than are shown in Figure 1065.110-1 of this section.

(c) *Configuration variations.* Since various configurations can produce equivalent results, you need not conform exactly to the drawings in this subpart. You may use other components—such as instruments, valves, solenoids, pumps and switches—to provide more information and coordinate the components' functions. Based on good engineering judgment, you may exclude other components that are not needed to maintain accuracy on some systems.

(d) *CFV-CVS component description.*

The flow characteristics of a Critical-Flow Venturi, Constant-Volume Sampler (CFV-CVS) are governed by the principles of fluid dynamics associated with critical flow. The CFV system is commonly called a constant-volume system (CVS) even though the mass flow varies. More properly, they are constant proportion sampling systems, because small CFVs in each of the sample lines maintain proportional sampling while temperatures vary. This CFV maintains the mixture's flow rate at choked flow, which is inversely proportional to the square root of the gas temperature, and the system computes the actual flow rate continuously. Because pressures and temperatures are the same at all venturi inlets, the sample volume is proportional to the total volume. The CFV-CVS sample system uses critical flow venturis for the bag sample or other sample lines (these are shown in the figure as flow control valves) and a critical flow venturi for the dilution tunnel. All venturis must be maintained at the same temperature.

(e) *EFC-CVS component description.*

The electronic flow control-CVS (EFC-CVS) system for sampling is identical to the CFV system described in paragraph (b) of this section, except that it adds electronic flow controllers (instead of sampling venturis), a subsonic venturi and an electronic flow controller for the CVS (instead of the critical flow venturi), metering valves, and separate flow meters (optional) to totalize sample flow volumes. The EFC sample system must conform to the following requirements:

- (1) The system must meet all the requirements in paragraph (b) of this section.
- (2) The ratio of sample flow to CVS flow must not vary by more than  $\pm 5$  percent from the test's set point.
- (3) Sample flow totalizers must meet the accuracy specifications in § 1065.150. You may obtain total volumes from the flow controllers, with our advance approval, if you can show they meet these accuracies.

(f) *Component description, PDP-CVS.*

The positive-displacement pump-CVS (PDP-CVS) system for sampling is identical to the CFV system described in paragraph (b) of this section, except for the following changes:

- (1) Include a heat exchanger.
- (2) Use positive-displacement pumps for the CVS flow and sampling-system flow. You do not need sampling venturis or a venturi for the dilution tunnel. All pumps must operate at a constant flow rate.
- (3) All pumps must operate at a nominally constant temperature. Maintain the gas mixture's temperature—measured at a point just ahead of the positive-displacement pump (and after the heat exchanger for the main CVS pump)—within  $\pm 10^{\circ}\text{F}$  ( $\pm 5.6^{\circ}\text{C}$ ) of the average operating temperature observed during the test. (You may estimate the average operating temperature from the temperatures observed during similar tests.) The system for measuring temperature (sensors and readout) must have an accuracy and precision of  $\pm 3.4^{\circ}\text{F}$  ( $1.9^{\circ}\text{C}$ ), and response time consistent with good engineering judgment.

(g) *Mixed systems.* You may combine elements of paragraphs (d), (e), and (f) consistent with good engineering judgment. For example, you may control the CVS flow rate using a CFV, and control sample flow rates using electronic flow controllers.

#### **§ 1065.115 Exhaust gas sampling system; compression-ignition engines. ~~Reserved~~**

(a) General. The exhaust gas sampling system described in this paragraph is designed to measure the true mass of both gaseous and particulate emissions in the exhaust of heavy-duty diesel engines, and particulate emissions in the exhaust of all heavy-duty engines. This system utilizes the constant volume sampling (CVS) concept of measuring the combined mass emissions of THC, NO<sub>x</sub>, CH<sub>4</sub> (if applicable) CO, CO<sub>2</sub> and particulate matter. In the CVS concept of measuring mass emissions, two conditions must be satisfied: the total volume of the mixture of exhaust and dilution air must be measured, and a continuously proportioned volume of sample must be collected for analysis. Mass emissions are determined from the

sample concentration and total flow over the test period. For all emission measurement systems described in this section, multiple or redundant systems may be used during a single test. Statistical averages of data from multiple systems may be used to calculate test results, consistent with good engineering judgment. Weighted averages are allowed, where appropriate. Statistical outliers may be discarded, but all results must be reported. If the Administrator determines that the statistical analysis is not consistent with good engineering judgment, he/she may determine compliance from the arithmetic mean of the results. A continuously integrated system may be used for THC, NO<sub>x</sub>, CO and CO<sub>2</sub> measurement. The use of proportional bag sampling for sample integration is allowed for THC, NO<sub>x</sub>, CO, and CO<sub>2</sub> measurement, but requirements specific to bag sampling from diesel exhaust must be met for the THC and NO<sub>x</sub> emissions measurements. CH<sub>4</sub> measurement for calculation of NMHC (if applicable) is measured using GC-FID analysis of a proportional bag sample. The mass of gaseous emissions is determined from the sample concentration and total flow over the test period. The mass of particulate emissions is determined from a proportional mass sample collected on a filter and from the sample flow and total flow over the test period. As an option, the measurement of total fuel mass consumed over a cycle may be substituted for the exhaust measurement of CO<sub>2</sub>. General requirements are as follows:

- (1) This sampling system requires the use of a CVS. The CVS system may use a positive displacement pump (PDP), subsonic venturi (SSV), or a critical flow venturi (CFV) for controlling CVS flow rate. PDP systems must use a heat exchanger. CFV systems may use either a heat exchanger or electronic flow compensation. When electronic flow compensation is used, the CFV may be replaced by a subsonic venturi (SSV) as long as the CVS concept is maintained (i.e., a constant volumetric flow-rate through the CVS is maintained for the duration of the test). Figure N07-1 is a schematic drawing of the CVS system.
- (2) The THC analytical system for diesel engines requires a heated flame ionization detector (HFID) and heated sample system (191 ± 11 °C) using either:
  - (i) Continuously integrated measurement of diluted THC meeting the minimum requirements and technical specifications contained in paragraph(b)(3) of this section. Unless compensation for varying mass flow is made, a constant mass flow system must be used to ensure a proportional sample; or
  - (ii) Heated (191 ± 11 °C) proportional bag sampling systems for hydrocarbon measurement will be allowed if the bag sampling system meets the performance specifications for outgassing and permeability as defined in paragraph (b) (2) of this section.
- (3) CH<sub>4</sub> measurement, if applicable, shall be conducted using a proportional bag sampling system with subsequent analysis using a gas chromatograph and FID.

(4) [Reserved]

(5) [Reserved]

(6) The CO and CO<sub>2</sub> analytical system requires:

- (i) Bag sampling and analytical capabilities, as shown in Figure N07-1; or
- (ii) Continuously integrated measurement of diluted CO and CO<sub>2</sub> meeting the minimum requirements and technical specifications contained in paragraph (b)(5) of this section. Unless compensation for varying flow is made, a constant flow system must be used to ensure a proportional sample; and

(7) The NO<sub>x</sub> analytical system requires:

- (i) Continuously integrated measurement of diluted NO<sub>x</sub> meeting the minimum requirements and technical specifications contained in paragraph (b)(5) of this section. Unless compensation for varying flow is made, a constant flow system must be used to ensure a proportional sample.
- (ii) Bag sampling and analytical capabilities, as shown in Figure N07-1 (or Figure 07-2) will be allowed provided that sample gas temperature is maintained above the sample's aqueous dewpoint at all times during collection and analysis.

(8) The mass of particulate in the exhaust is determined via filtration. The particulate sampling system requires dilution of the exhaust to a temperature of 47 °C ± 5 °C, measured upstream of a single high-efficiency sample filter (as close to the filter as practical).

(9) Since various configurations can produce equivalent results, exact conformance with these drawings is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the components of the system. Other components, such as snubbers, which are not needed to maintain accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgment.

(10) Other sampling and/or analytical systems may be used if approved as per §1065.10.

(b) Component description. The components necessary for exhaust sampling shall meet the following requirements:

(1) The intent of this measurement procedure is to perform the sample cooling primarily via dilution and mixing with air rather than via heat transfer to the surfaces of the sampling system. In addition the CVS must conform to the following requirements:

(i) The flow capacity of the CVS must be sufficient to maintain the diluted exhaust stream at the temperatures required for the measurement of particulate and hydrocarbon emission noted below and at, or above, the temperatures where aqueous condensation in the exhaust gases could occur. This is achieved by the following method. The flow capacity of the CVS must be sufficient to maintain the diluted exhaust stream in the primary dilution tunnel at a temperature of 191 °C or less at the sampling zone and as required to prevent condensation at any point in the dilution tunnel. Gaseous emission samples may be taken directly from this sampling point. An exhaust sample must then be taken at this point to be diluted a second time for use in determining particulate emissions. The secondary dilution system must provide sufficient secondary dilution air to maintain the double-diluted exhaust stream at a temperature of  $47\text{ °C} \pm 5\text{ °C}$ , measured at a well-mixed point located between 20 cm downstream of the filter face or 20 cm upstream of the filter face.

(ii) For the CVS, either a heat exchanger (i.e. CFV-CVS) or electronic flow compensation (i.e. EFC-CFV-CVS or EFC-SSV-CVS), which also includes the particulate sample flows is required. Refer to Figure N07-1.

(iii) When a heat exchanger is used, the gas mixture temperature, measured at a point immediately ahead of the critical flow venturi, shall be within  $\pm 11\text{ °C}$  of the average operating temperature observed during the test with the simultaneous requirement that aqueous condensation does not occur. The temperature measuring system (sensors and readout) shall have an accuracy and precision of  $\pm 1.9\text{ °C}$ . For systems utilizing a flow compensator to maintain proportional sampling, the requirement for maintaining constant temperature is not necessary.

(iv) The primary dilution air and secondary dilution air:

(A) Shall have a primary and secondary dilution air temperature equal to or greater than 15 °C.

(B) Primary dilution air shall be filtered at the dilution air inlet. The manufacturer of the primary dilution air filter shall state that the filter design has successfully achieved a minimum particle removal efficiency of 98% (less than 0.02 penetration) as determined using test method ASTM F 1471 - 93 (incorporated by reference at §1065.1010).

Secondary dilution air shall be filtered at the dilution air inlet using a high-efficiency particulate air filter (HEPA). The HEPA filter manufacturer shall state the HEPA filter design has successfully achieved a minimum particle removal efficiency of 99.97% (less than 0.0003 penetration) as determined using ASTM test method F 1471 - 93. It is recommended that the primary dilution air be filtered using a HEPA filter. EPA intends to utilize HEPA filters to condition primary dilution air in its test facilities. It is also recommended that charcoal hydrocarbon scrubbers not be used to precondition dilution air because these scrubbers may store and release adsorbed hydrocarbons in an unpredictable manner. It is acceptable to use a booster blower upstream or downstream of a HEPA filter in the primary dilution tunnel (and upstream of the introduction of

engine exhaust into the CVS) to compensate for the additional pressure loss associated with the filter. The design of any booster blower located downstream of the filter should minimize the introduction of additional particulate matter into the CVS.

(C) Primary dilution air may be sampled to determine background particulate levels, which can then be subtracted from the values measured in the diluted exhaust stream. In the case of primary dilution air, the background particulate filter sample shall be taken immediately downstream of the dilution air filter and upstream of the engine exhaust flow (Figure N07-1). The provisions of paragraphs (b) (7) of this section, also apply to the measurement of background particulate matter, except that the filter temperature must be maintained below 52°C.

(2) Heated proportional bag sampling systems. If a heated ( $191 \pm 11$  °C) proportional bag sampling system is used for THC measurement, sample bags must demonstrate minimal outgassing and permeability by passing the following performance test:

(i) Performance test for sample bag HC outgassing and CO<sub>2</sub> permeability. Bring the bag system to its operational temperature. Fill the heated sample bag with a nominal mixture of 1% CO<sub>2</sub> in N<sub>2</sub>. Perform an initial measurement of CO<sub>2</sub> and THC from the sample bag, and repeat the measurement after one hour. Acceptable performance criteria are < 2% decrease of the initial CO<sub>2</sub> reading and < 1 ppmC THC.

(ii) [Reserved]

(3) Continuous HC measurement system. (i) The continuous HC sample system (as shown in Figure N07-1) uses an "overflow" zero and span system. In this type of system, excess zero or span gas spills out of the probe when zero and span checks of the analyzer are made. The "overflow" system may also be used to calibrate the HC analyzer.

(ii) No other analyzers may draw a sample from the continuous HC sample probe, line or system, unless a common sample pump is used for all analyzers and the sample line system design reflects good engineering practice.

(iii) The overflow gas flow rates into the sample line shall be at least 105% of the sample system flow rate.

(iv) The overflow gases shall enter the heated sample line as close as practicable to the outside surface of the CVS duct or dilution tunnel.

(v) The continuous HC sampling system shall consist of a probe (which must raise the sample to the specified temperature) and, where used, a sample transfer system (which must maintain the specified temperature). The continuous hydrocarbon sampling system (exclusive of the probe) shall:

(A) Maintain a wall temperature of  $191^{\circ}\text{C} \pm 11^{\circ}\text{C}$  as measured at every separately controlled heated component (i.e., filters, heated line sections), using permanent thermocouples located at each of the separate components.

(B) Have a wall temperature of  $191^{\circ}\text{C} \pm 11^{\circ}\text{C}$  over its entire length. The temperature of the system shall be demonstrated by profiling the thermal characteristics of the system at initial installation and after any major maintenance performed on the system. The temperature profile of the HC sampling system shall be demonstrated by inserting thermocouple wires (typically Teflon<sup>TM</sup> coated for ease of insertion) into the sampling system assembled in-situ where possible, using good engineering judgment. The wire should be inserted up to the HFID inlet. Stabilize the sampling system heaters at normal operating temperatures. Withdraw the wires in increments of 5 cm to 10 cm (2 inches to 4

inches) including all fittings. Record the stabilized temperature at each position. The system temperature will be monitored during testing at the locations and temperature described in this section. (Note: It is understood that profiling of the sample line can be done under flowing conditions also as required with the probe. This test may be cumbersome if test facilities utilize long transfer lines and many fittings; therefore it is recommended that transfer lines be kept as short as possible and the use of fittings should be kept minimal.)

(C) Maintain a gas temperature of  $191^{\circ}\text{C} \pm 11^{\circ}\text{C}$  immediately before the heated filter and HFID. These gas temperatures will be determined by a temperature sensor located immediately upstream of each component.

(vi) The continuous hydrocarbon sampling probe shall:

(A) Be defined as the first 25.4 cm (10in) to 76.2 cm (30 in) of the continuous hydrocarbon sampling system;

(B) Have a 0.483 cm (0.19 in) minimum inside diameter;

(C) Be installed in the primary dilution tunnel at a point where the dilution air and exhaust are well mixed (i.e., approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel);

(D) Be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies; and

(E) Increase the gas stream temperature to  $191^{\circ}\text{C} \pm 11^{\circ}\text{C}$  by the exit of the probe. The ability of the probe to accomplish this shall be demonstrated at typical sample flow rates using the insertion thermocouple technique at initial installation and after any major maintenance. Compliance with the temperature specification shall be demonstrated by monitoring during each test the temperature of either the gas stream or the wall of the sample probe at its terminus.

(vii) The response time of the continuous measurement system shall be no greater than:

(A) 1.5 seconds from an instantaneous step change at the port entrance to the analyzer to within 90 percent of the step change;

(B) 10 seconds from an instantaneous step change at the entrance to the sample probe or overflow span gas port to within 90 percent of the step change. Analysis system response time shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets if necessary; and

(C) For the purpose of verification of response times, the step change shall be at least 60 percent of full-scale chart deflection.

(4) Primary-dilution tunnel. (i) The primary dilution tunnel shall be:

(A) Small enough in diameter to cause turbulent flow (Reynolds Number greater than 4000) and of sufficient length to cause complete mixing of the exhaust and dilution air. Good engineering judgment shall dictate the use of mixing plates and mixing orifices to ensure a well-mixed sample. To verify mixing, EPA recommends flowing a tracer gas (i.e. propane or  $\text{CO}_2$ ) from the raw exhaust inlet of the dilution tunnel and measuring its concentration at several points along the axial plane at the sample probe. Tracer gas concentrations should remain nearly constant (i.e. within 2%) between all of these points.

(B) At least 8 inches (20 cm) in diameter.

(C) Constructed of electrically conductive material, which does not react with the exhaust components.

(D) Electrically grounded.

(E) EPA recommends that the tunnel should have minimal thermal capacitance such that the temperature of the walls tracks with the temperature of the diluted exhaust.

(ii) The temperature of the diluted exhaust stream inside of the primary dilution tunnel shall be sufficient to prevent water condensation.

(iii) The engine exhaust shall be directed downstream at the point where it is introduced into the primary dilution tunnel.

(5) Continuously integrated NO<sub>x</sub>, CO, and CO<sub>2</sub> measurement systems. (i) The sample probe shall:

(A) Be in the same plane as the continuous HC probe, but shall be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influences of any wakes or eddies; and

(B) Heated and insulated over the entire length, to prevent water condensation, to a minimum temperature of 131°F (55 °C). Sample gas temperature immediately before the first filter in the system shall be at least 131 °F (55 °C).

(ii) The continuous NO<sub>x</sub>, CO, or CO<sub>2</sub> sampling and analysis system shall conform to the specifications of subpart D of this part, with the following exceptions:

(A) The system components required to be heated need only be heated to prevent water condensation, the minimum component temperature shall be 131 °F (55 °C);

(B) The system response shall be no greater than 10 seconds. Analysis system response time shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary;

(D) All analytical gases shall conform to the specifications of §1065 Subpart C;

(E) Any range on a linear analyzer below 100 ppm shall have and use a calibration curve conforming to §1065 Subpart D; and

(F) The NO<sub>x</sub> measurement accuracy requirements shall be as follows.

(a) Minimum limit. (1) The minimum limit of an analyzer must be equal to or less than one-half of the average diluted concentration for an engine emitting the maximum amount of the applicable pollutant allowed by the applicable standard. For example, if with a given dilution and sampling system, an engine emitting NO<sub>x</sub> at the level of the standard (e.g., 0.20 g/bhp-hr NO<sub>x</sub>) would result in an average NO<sub>x</sub> concentration of 1.0 ppm in the diluted sample, then the minimum limit for the NO<sub>x</sub> analyzer must be less than or equal to 0.5 ppm.

(2) For the purpose of this section, "minimum limit" means the lowest of the following levels:

(i) The lowest NO<sub>x</sub> concentration in the calibration curve for which an accuracy of ±2 percent of point has been demonstrated as specified in paragraph (a)(3) of this section; or

(ii) Any NO<sub>x</sub> concentration for which the test facility has demonstrated sufficient accuracy to the Administrator's satisfaction prior to the start of testing, such that it will allow a meaningful determination of compliance with respect to the applicable standard.

(3) For determination of the analyzer's minimum limit, a NO<sub>x</sub> concentration that is less than or equal to one-half of the average NO<sub>x</sub> concentration determined in (a)(1) of this section shall be measured by the oxides of nitrogen analyzer following the analyzer's monthly periodic calibration. This measurement must be made to ensure the accuracy of the calibration curve to within ±2 percent of point accuracy of the appropriate least-squares fit, at less than or equal to one half of the average expected diluted NO<sub>x</sub> concentration determined in (a)(1) of this section.

(b) Measurement accuracy - Bag sampling. Analyzers used for bag analysis must be operated such that the measured concentration falls between 15 and 100 percent of full scale, with the following exception: concentrations below 15 percent of full scale may be used if the minimum limit of the analyzer within the range meets the requirement of paragraph (a) of this section.

(c) Measurement accuracy - Continuous measurement. (1) Analyzers used for continuous analysis must be operated such that the measured concentration falls between 15 and 100 percent of full scale, with the following exceptions:

(i) Concentrations below 15 percent of full scale may be used if the minimum limit of the analyzer within the range meets the requirement of paragraph (a) of this section.

(ii) Analyzer response over 100% of full scale may be used if it can be shown that readings in this range are accurate.

(2) If the analyzer response exceeds the level allowed by paragraph (c)(1)(ii) of this section, the test must be repeated using a higher range and both results must be reported. The Administrator may waive this requirement under §1065.10.

(d) If a gas divider is used it shall be used according to the procedures contained in paragraphs (a) and (b) of this section.

(iii) The signal output of analyzers with non-linear calibration curves shall be converted to concentration values by the calibration curve(s) before flow correction (if used) and subsequent integration takes place.

(6) Particulate sampling system. This method collects a proportional sample from the primary tunnel, and then transfers this sample to a secondary dilution tunnel where the sample is further diluted. The double-diluted sample is then passed through the collection filter. Proportionality (i.e., mass flow ratio) between the primary tunnel flow rate and the sample flow rate must be maintained within  $\pm 5\%$ , excluding the first 10 seconds of the test at start-up. The requirements for this system are:

(i) The particulate sample transfer tube shall be configured and installed so that:

(A) The inlet faces upstream in the primary dilution tunnel at a point where the primary dilution air and exhaust are well mixed.

(B) The particulate sample exits on the centerline of the secondary tunnel.

(ii) The entire particulate sample transfer tube shall be:

(A) Sufficiently distant (radially) from other sampling probes (in the primary dilution tunnel) so as to be free from the influence of any wakes or eddies produced by the other probes.

(B) 0.85 cm minimum inside diameter.

(C) No longer than 36 in (91 cm) from inlet plane to exit plane.

(D) Designed to minimize the diffusional and thermophoretic deposition of particulate matter during transfer (i.e., sample residence time in the transfer tube should be as short as possible, temperature gradients between the flow stream and the transfer tube wall should be minimized). Double-wall, thin-wall, air-gap insulated, or a controlled heated construction for the transfer tube is recommended.

(E) Constructed such that the surfaces exposed to the sample shall be an electrically conductive material, which does not react with the exhaust components, and this surface shall be electrically grounded so as to minimize electrostatic particulate matter deposition.

(iii) The secondary dilution air shall be at a temperature equal to or greater than 15 °C.

(iv) The secondary-dilution tunnel shall be constructed such that the surfaces exposed to the sample shall be an electrically conductive material, which does not react with the exhaust components, and this surface shall be electrically grounded so as to minimize electrostatic particulate deposition.

(v) Additional dilution air must be provided so as to maintain a sample temperature of  $47\text{ °C} \pm 5\text{ °C}$  upstream of the sample filter. Temperature shall be measured with a thermocouple with a 3/16" shank, having thermocouple wires with a gage diameter 24 AWG or smaller, a bare-wire butt-welded junction; or other suitable temperature measurement with an equivalent or faster time constant and an accuracy and precision of  $\pm 1.9\text{ °C}$ .

(vi) The filter holder assembly shall be located within 12.0 in (30.5 cm) of the exit of the inertial preclassifier.

(vii) The face velocity through the sample filter shall not exceed 100 cm/s (face velocity is defined as the standard volumetric sample flow rate (i.e., scm<sup>3</sup>/sec) divided by the sample filter stain area (i.e., cm<sup>2</sup>)).

(7) Particulate sampling. (i) Filter specifications. (A) Polytetrafluoroethylene (PTFE or Teflon<sup>TM</sup>) coated borosilicate glass fiber high-efficiency filters or polytetrafluoroethylene (PTFE or Teflon<sup>TM</sup>) high-efficiency membrane filters with an integral support ring of polymethylpentene (PMP) or equivalent inert material are required. Filters shall have a minimum clean filter efficiency of 99% as measured by the ASTM D2986-95a DOP test (incorporated by reference at section 86.1).

(B) Particulate filters must have a diameter of  $46.50 \pm 0.6$  mm ( 38 mm minimum stain diameter).

(C) The dilute exhaust is simultaneously sampled by a single high-efficiency filter during the cold-start test and by a second high efficiency filter during the hot-start test.

(D) It is recommended that the filter loading should be maximized consistent with temperature requirements.

(ii) Filter holder assembly. The filter holder assembly shall comply with the specifications set forth for ambient PM measurement in 40 CFR 50 Appendix L 7.3.5, figures L-25 and L-26, with the following exceptions:

(A) The material shall be 300 series stainless steel instead of anodized aluminum.

(B) The 2.84 cm diameter entrance to the filter holder may be adapted, using sound engineering judgment and leak-free construction, to an inside diameter no smaller than 0.85 cm, maintaining the 12.5 ° angle from the inlet of the top filter holder to the area near the sealing surface of the top of the filter cartridge assembly. Figure N07-2 shows acceptable variation from the design in 40 CFR 50 Appendix L. Similar variations using sound engineering design are also acceptable provided that they provide even flow distribution across the filter media and a similar leak-free seal with the filter cartridge assembly.

(C) If additional or multiple filter cartridges are stored in a particulate sampler as part of an automatic sequential sampling capability, all such filter cartridges, unless they are installed in the sample flow (with or without flow established) shall be covered or sealed to prevent communication of semi-volatile matter from filter to filter; contamination of the filters before and after sampling; or loss of volatile or semi-volatile particulate matter after sampling.

(iii) Filter cartridge assembly. The filter cartridge assembly shall comply with the specifications set forth for ambient PM measurement in 40 CFR 50 Appendix L 7.3.5, figures L-27, L-28, and L-29, with the following exceptions:

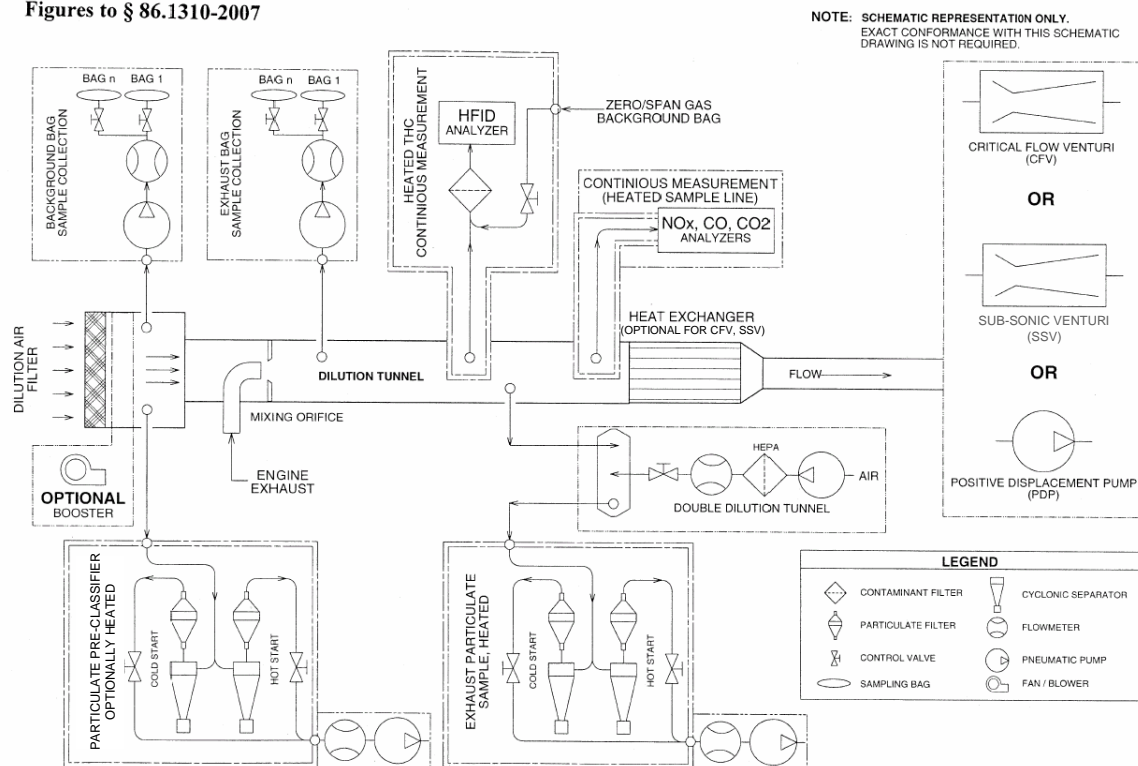
(A) In addition to the specified Delrin<sup>TM</sup> material, 300 series stainless steel, polycarbonate or acrylonitrile/butadiene/styrene (ABS) resin, conductive polypropylene or a combination of these materials may also be used.

(B) A bevel introduced on the inside diameter of the entrance to the filter cartridge, as used by some commercially available automated sequential particulate filter cartridge changers, is also acceptable (see Figure N07-3).

(iv) Particle preclassifier. A particle preclassifier shall be installed immediately upstream of the filter holder assembly (N07-1). A particle preclassifier may be used for a test only

if the filters used in conjunction with the preclassifier comply with paragraph (i) of this subpart. The purpose of the preclassifier is to remove coarse, mechanically generated particles (e.g., rust from the engine exhaust system or carbon sheared from the sampling system walls) from the sample flow stream while allowing combustion-generated particles to pass through to the filter. The preclassifier may be either an inertial impactor or a cyclonic separator. The preclassifier manufacturer 50 % cutpoint particle diameter shall be between 2.5  $\mu\text{m}$  and 10  $\mu\text{m}$  at the volumetric flow rate selected for sampling of particulate matter emissions. Sharpness of cut is not specifically defined, but the preclassifier geometry shall allow at least 99% of the mass concentration of 1  $\mu\text{m}$  particles to pass through the exit of the preclassifier to the filter at the volumetric flow rate selected for sampling particulate matter emissions. Periodic servicing of the preclassifier, as per preclassifier manufacturer instructions, will be necessary to prevent a buildup of mechanically separated particles. The particle preclassifier may be made integral with the top of the filter holder assembly. The preclassifier may also be made integral with a mixing-tee for introduction of secondary dilution air, thus replacing the secondary dilution tunnel; provided that the preclassifier provides sufficient mixing.

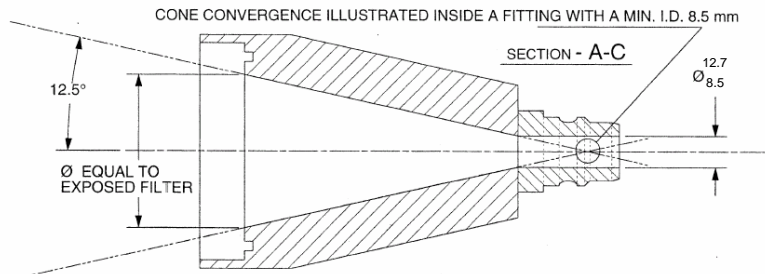
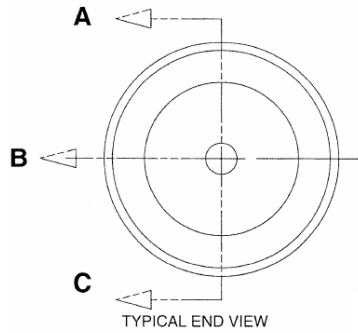
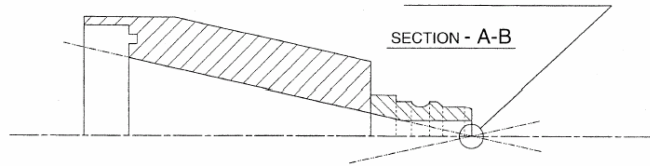
Figures to § 86.1310-2007



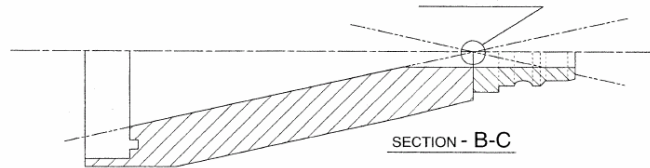
N07-1 GASEOUS AND PARTICULATE EMISSIONS SAMPLING SYSTEM (CONSTANT VOLUME SAMPLER – CVS)

**METRIC**  
mm

CONE CONVERGENCE ILLUSTRATED AT THE UPSTREAM END OF A FITTING WITH A MIN. I.D. 8.5 MM  
NOTE: THE FITTING IS MODIFIED TO MAINTAIN 12.5 DEGREES TO THE CONVERGENCE.



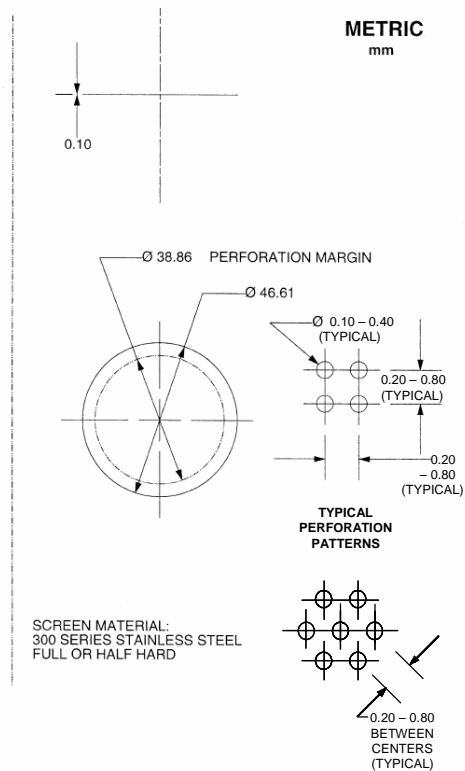
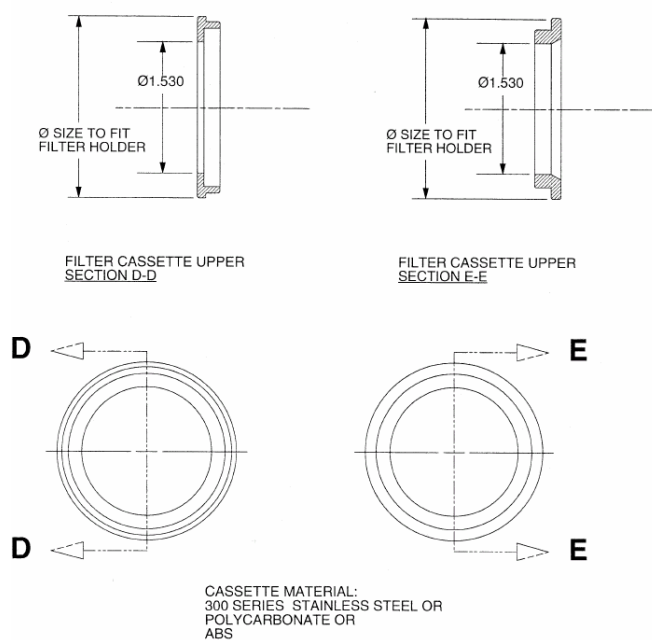
CONE CONVERGENCE ILLUSTRATED AT THE DOWNSTREAM END OF A FITTING WITH A MIN. I.D. 8.5 MM  
NOTE: THE FITTING IS MODIFIED TO MAINTAIN 12.5 DEGREES TO THE CONVERGENCE.



**NOTES:**

- 1) MATERIAL, 300-SERIES STAINLESS STEEL
- 2) ROUGHNESS, ALL WETTED SURFACES, 32 RMS
- 3) BREAK ALL SHARP EDGES

**N07-2 FILTER HOLDER GEOMETRY**



#### N07-3 FILTER CASSETTE AND SCREEN

§ 1065.120 Raw sampling. [Reserved]

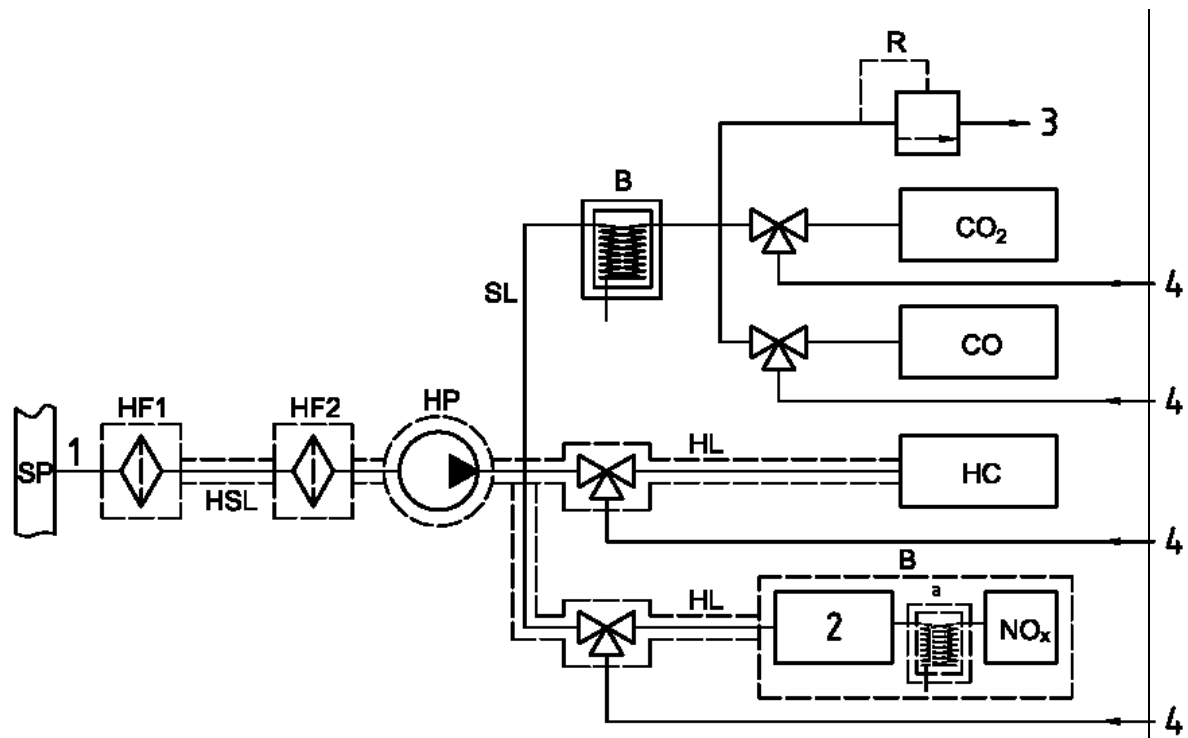


Figure 3 — Flow diagram of raw exhaust gas analysis system for CO, CO<sub>2</sub>, NO<sub>x</sub>, HC and O<sub>2</sub>

### Components of figures 2 and 3

#### General

All components in the sampling gas path must be maintained at the temperatures specified for the respective systems.

#### SP1 — raw exhaust gas sampling probe (figure 2 only)

NOTE If exhaust pulsations or engine vibrations are likely to change the sampling probe, the wall thickness of the probe may be enlarged with the agreement of the parties involved.

#### SP2 — dilute exhaust gas HC sampling probe (figure 3 only)

#### SP3 — dilute exhaust gas CO, CO<sub>2</sub>, NO<sub>x</sub> sampling probe (figure 3 only)

The probe shall:

- . be in the same plane as SP2;
- . be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- . be heated and insulated over its entire length to a minimum temperature of 328 K (55 °C) to prevent water condensation.

#### HSL1 — heated sampling line

The sampling line provides a gas sample from a single probe to the split point(s) and the HC analyser.

The sampling line shall:

- . be made of stainless steel or PTFE.
- a) For non-methanol-fuelled engines

If the temperature of the exhaust gas at the sampling probe is equal to or below 463 K (190 °C), maintain a wall

temperature of 463 K  $\pm$  10 K (190 °C  $\pm$  10 °C) as measured at every separately controlled heated section.

If the temperature of the exhaust gas at the sampling probe is above 463 K (190 °C), maintain a wall temperature greater than 453 K (180 °C).

Immediately before the heated filter F2 and the HFID, maintain a gas temperature of 463 K  $\pm$  10 K (190 °C  $\pm$  10 °C).

**HSL2 — heated NO<sub>x</sub> (and NH<sub>3</sub>) sampling line**

The sampling line shall:

. maintain a wall temperature of 328 K to 473 K (55 °C to 200 °C), up to the converter C when using a cooling bath B, and up to the analyser when a cooling bath B is not used;

. be made of stainless steel or PTFE.

NOTE Since the sampling line need only be heated to prevent condensation of water and sulfuric acid, the sampling line

temperature will depend on the sulfur content of the fuel.

**SL — sampling line for CO, (CO<sub>2</sub>, O<sub>2</sub>)**

The line shall be made of PTFE or stainless steel. It may be heated or unheated.

**BK — background bag (optional; figure3 only)**

For the measurement of the background concentrations.

**BG — sample bag (optional; figure3 CO and CO<sub>2</sub> only)**

For the measurement of the sample concentrations.

**F1 — heated pre-filter (optional)**

The temperature shall be the same as HSL1.

**F2 — heated filter**

The filter shall extract any solid particles from the gas sample before the analyser. The temperature shall be the

same as HSL1. The filter shall be changed as needed.

**P — heated sampling pump**

The pump shall be heated to the temperature of HSL1.

**HC**

Heated flame ionization detector (HFID) for the determination of the hydrocarbons. The temperature shall be kept

at 453 K to 473 K (180 °C to 200 °C)

**CO, CO<sub>2</sub>**

NDIRs for the determination of carbon monoxide and carbon dioxide.

**NO**

CLD or HCLD for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of 328 K to 473 K (55 °C to 200 °C).

**C — converter**

A converter shall be used for the catalytic reduction of NO<sub>2</sub> to NO prior to analysis in the CLD or HCLD.

**O<sub>2</sub>**

PMD, ZRDO or ECS for the determination of oxygen.

**B — cooling bath (optional)**

The bath shall be maintained at a temperature of 273 K to 277 K (0 °C to 4 °C) by ice or refrigerator. It is optional if the analyser is free from water vapour interference as determined in 8.9.2 and 8.9.3. If water is removed by condensation, the sample gas temperature or dew point shall

be monitored either within the water trap or downstream. The sample gas temperature or dew point shall not exceed 280 K (7 °C). Chemical dryers are not allowed for removing water from the sample.

**Response time:** Difference in time between a rapid change of the component to be measured at the reference point and the appropriate change in the response of the measuring system whereby the change of the measured component is at least 60% FS and takes place in less than 0.1 second

NOTE 2 The system response time ( $t_{90}$ ) consists of the delay time to the system and of the rise time of the system.

NOTE 3 The response time may vary dependent on where the reference point for the change of the component to be measured is defined, either at the sampling probe or directly at the port entrance of the analyzer; in this International Standard, the sampling probe is defined as the reference point.

**Delay time:** Time between the change of the component to be measured at the reference point and a system response of 10% of the final reading ( $t_{10}$ )

NOTE 4 For the gaseous components, this is basically the transport time of the measured component from the sampling probe to the detector.

NOTE 5 See NOTE 3. For the delay time, the sampling probe is defined as the reference point.

**Rise time:** Time between the 10% and 90% response of the final reading ( $t_{90} - t_{10}$ )

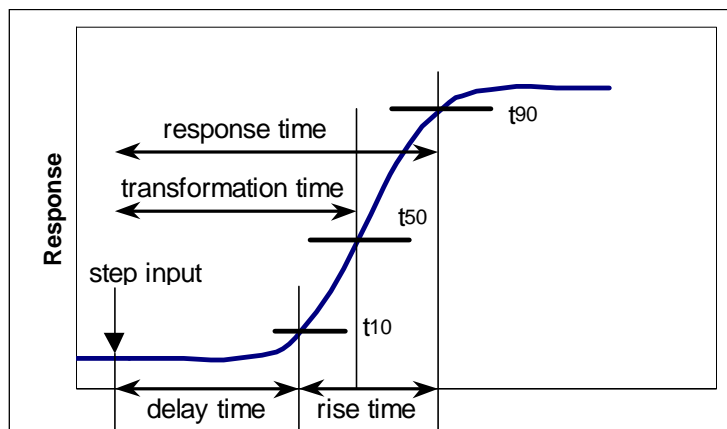
NOTE 6 This is the instrument response after the component to be measured has reached the instrument.

NOTE 7 See NOTE 3. For the rise time, the sampling probe is defined as the reference point.

**Transformation time:** Time between the change of the component to be measured at the reference point and a system response of 50% of the final reading ( $t_{50}$ )

NOTE 8 See NOTE 3. For the transformation time, the sampling probe is defined as the reference point.

NOTE 9 The transformation time is used for the signal alignment of different measurement instruments.



**Figure 1 — Definitions of system response**

**§ 1065.125 Analyzers (overview/general response characteristics).**

(a) *General.* The following sections and subparts describe the specifications for analyzers and analytical equipment:

(1) The analyzers for measuring hydrocarbon, NOX, CO, and CO2 emission concentrations are specified in § 1065.130 through § 1065.140. (2) The analytical equipment for measuring particulate emissions is specified in Subpart H of this part.

(3) The analytical equipment for measuring emissions of oxygenated compounds (for example, methanol) is specified in Subpart I of this part. (4) The analytical equipment for measuring in-use emissions is specified in Subpart J of this part.

(b) *Response time.* Analyzers must have the following response characteristics:

(1) For steady-state testing and transient testing with bag sample analysis, the analyzer must reach at least 90 percent of its final response within 5.0 seconds after any step change to the input concentration at or above 80 percent of full scale.

(2) For transient testing with continuous measurement, the analyzer must reach at least 90 percent of its final response within 1.0 second after any step change to the input concentration at or above 80 percent of full scale.

(c) *Precision and noise.* Analyzers must meet the following characteristics for precision and noise:

(1) Precision must be no worse than  $\pm 1$  percent of full-scale concentration for each range used above 155 ppm (or ppmC), or  $\pm 2$  percent for each range used below 155 ppm (or ppmC). For this paragraph (c)(1), we define precision as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas.

(2) Peak-to-peak response to zero and calibration or span gases over any 10-second period must be no more than 2 percent of full-scale chart deflection on all ranges used.

(d) *Drift.* Analyzers must meet specifications for zero-response and span drift.

(1) The zero-response drift during one hour must be less than 2 percent of full scale chart deflection on the lowest range used. Zero-response is the mean response, including noise, to a zero-gas during a 30-second interval.

(2) The span drift during one hour must be less than 2 percent of full-scale chart deflection on the lowest range used. Span is the difference between the span-response and the zero-response. Span-response is the mean response, including noise, to a span gas during a 30-second interval.

(e) *Calibration.* See subpart D of this part for specifications to calibrate analyzers.

The accuracy of measurements must be such that the maximum tolerances shown in Table 3 in appendix A of this subpart are not exceeded. Calibrate all equipment and analyzers according to the frequencies shown in Table 3 in appendix A of this subpart.

TABLE 3—MEASUREMENT ACCURACY AND CALIBRATION FREQUENCY

No.	Item	Calibration accuracy <sup>1</sup>	Calibration frequency
1	Engine speed .....	$\pm 2\%$ .....	30 days.
2	Torque .....	Larger of $\pm 2\%$ of point or $\pm 1\%$ of engine maximum.	30 days.
3	Fuel consumption (raw measurement) .....	$\pm 2\%$ of engine maximum .....	30 days.
4	Air consumption (raw measurement) .....	$\pm 2\%$ of engine maximum .....	As required.
5	Coolant temperature .....	$\pm 2^\circ\text{K}$ .....	As required.
6	Lubricant temperature .....	$\pm 2^\circ\text{K}$ .....	As required.
7	Exhaust backpressure .....	$\pm 1.0\%$ of engine maximum ..	As required.

TABLE 3—MEASUREMENT ACCURACY AND CALIBRATION FREQUENCY—Continued

No.	Item	Calibration accuracy <sup>1</sup>	Calibration frequency
8	Inlet depression .....	1.0% of engine maximum .....	As required.
9	Exhaust gas temperature .....	±15°K .....	As required.
10	Air inlet temperature (combustion air) .....	±2°K .....	As required.
11	Atmospheric pressure .....	± 0.5% .....	As required.
12	Humidity (combustion air) (g of H <sub>2</sub> O/Kg of dry air) .....	± 0.5 .....	As required.
13	Fuel temperature .....	±2°K .....	As required.
14	Temperature with regard to dilution tunnel .....	±2°K .....	As required.
15	Dilution air humidity (g of H <sub>2</sub> O/Kg of dry air) .....	± 0.5 .....	As required.
16	HC analyzer .....	± 2% .....	Monthly or as required.
17	CO analyzer .....	± 2% .....	Once per 60 days or as required.
18	NO <sub>x</sub> analyzer .....	± 2% .....	Monthly or as required.
19	Methane analyzer .....	± 2% .....	Monthly or as required.
20	NO <sub>x</sub> converter efficiency check .....	90% .....	Monthly.
21	CO <sub>2</sub> analyzer .....	± 2% .....	Once per 60 days or as required.

<sup>1</sup> All accuracy requirements pertain to the final recorded value which is inclusive of the data acquisition system.

#### Analyzer accuracy and specifications.

##### (a) Measurement accuracy—general.

The analyzers must have a measuring range which allows them to measure the concentrations of the exhaust gas sample pollutants with the accuracies shown in Table 3 in Appendix A of this subpart.

(1) Response time. As necessary, measure and account for the response time of the analyzer.

(2) Precision. The precision of the analyzer must be, at worst, ±1 percent of full-scale concentration for each range. The precision is defined as 2.5 times the standard deviation(s) of 10 repetitive responses to a given calibration or span gas.

(3) Noise. The analyzer peak-to-peak response to zero and calibration or span gases over any 10-second period must not exceed 2 percent of full-scale chart deflection on all ranges used.

(4) Zero drift. The analyzer zero-response drift during a 1-hour period must be less than 2 percent of full-scale chart deflection on the lowest range used. The zero-response is defined as the mean response including noise to a zero-gas during a 30-second time interval.

(5) Span drift. The analyzer span drift during a 1-hour period must be less than 2 percent of full-scale chart deflection on the lowest range used. The analyzer span is defined as the difference between the span-response and the zero-response. The span-response is defined as the mean response including noise to a span gas during a 30-second time interval.

(b) Operating procedure for analyzers and sampling system. Follow the startup and operating instructions of the instrument manufacturer.

##### (c) Emission measurement accuracy— Bag sampling.

(1) Good engineering practice dictates that exhaust emission sample analyzer readings below 15 percent of full-scale chart deflection should generally not be used.

(2) Some high resolution read-out systems, such as computers, data loggers, and so forth, can provide sufficient accuracy and resolution below 15 percent of full scale. Such systems may be used provided that additional calibrations of at least 4 non-zero nominally equally spaced points, using good engineering judgement, below 15 percent of full scale are made to ensure the accuracy of the calibration curves. If a gas divider is used, the gas divider must conform to the accuracy requirements specified. The procedure in paragraph (c)(3) of this section may be used for calibration below 15 percent of full scale.

(3) The following procedure shall be followed:

(i) Span the analyzer using a calibration gas meeting the accuracy requirements within the operating range of the analyzer, and at least 90% of full scale.

(ii) Generate a calibration over the full concentration range at a minimum of 6, approximately equally spaced, points (e.g. 15, 30, 45, 60, 75, and 90 percent of the range of concentrations provided by the gas divider). If a gas divider or blender is being used to calibrate the analyzer and the requirements of paragraph (c)(2) of this section are met, verify that a second calibration gas between 10 and 20 percent of full scale can be named within 2 percent of its certified concentration.

(iii) If a gas divider or blender is being used to calibrate the analyzer, input the value of a second calibration gas (a span gas may be used for the CO<sub>2</sub> analyzer) having a named concentration between 10 and 20 percent of full scale. This gas shall be included on the calibration curve. Continue adding calibration points by dividing this gas until the requirements of paragraph (c)(2) of this section are met.

(iv) Fit a calibration curve for the full scale range of the analyzer using the calibration data obtained with both calibration gases.

(d) Emission measurement accuracy— continuous sampling.

Analyzers used for continuous analysis must be operated such that the measured concentration falls between 15 and 100 percent of full scale chart deflection. Exceptions to these limits are:

(1) The analyzer's response may be less than 15 percent or more than 100 percent of full scale if automatic range change circuitry is used and the limits for range changes are between 15 and 100 percent of full-scale chart deflection;

(2) The analyzer's response may be less than 15 percent of full scale if:

(i) Alternative (c)(2) of this section is used to ensure that the accuracy of the calibration curve is maintained below 15 percent.

(a) Prior to initial use and after major repairs, bench check each analyzer:

(b) Calibrations are performed as specified by the manufacturer.

(c) At least monthly, or after any maintenance which could alter calibration, the following calibrations and checks are performed.

(1) Leak check the vacuum side of the system.

(2) Check that the analysis system response time has been measured and accounted for.

(3) Verify that the automatic data collection system (if used) meets the requirements found in Table 3 in appendix A of this subpart.

(4) Check the fuel flow measurement instrument to insure that the specifications in Table 3 in appendix A of this subpart are met.

(d) Verify that all NDIR analyzers meet the water rejection ratio and the CO<sub>2</sub> rejection ratio as specified in § 89.318.

(e) Verify that the dynamometer test stand and power output instrumentation meet the specifications in Table 3 in appendix A of this subpart.

### **§ 1065.130 Hydrocarbon analyzers.**

This section describes the requirements for flame ionization detectors (FIDs) used to measure hydrocarbons.

(a) Fuel the FID with a mixture of hydrogen in helium and calibrate it using propane.

(b) If you use a heated FID (required only for diesels and two-stroke, spark ignition engines), keep the temperature  $191 \pm 1^\circ\text{C}$ .

(c) Use an overflow sampling system for heated continuous FIDs. (In an overflow system excess zero gas or span gas spills out of the probe when you are doing zero or span checks.)

(d) Do not premix the FID fuel and burner air.

(e) Make sure the FID meets accuracy and precision specifications in ISO 8178-1 (incorporated by reference in § 1065.1010).

#### Hydrocarbon analyzer specifications.

(a) Hydrocarbon measurements are to be made with a heated flame ionization detector (HFID) analyzer.

(b) Option. A non-heated flame ionization detector (FID) that measures hydrocarbon emissions on a dry basis is permitted for gasoline-fueled testing provided, that equivalency is demonstrated to the Administrator.

(c) The analyzer shall be fitted with a constant temperature oven housing the detector and sample-handling components. It shall maintain temperature with  $2^\circ\text{C}$  of the set point. The detector, oven, and sample-handling components within the oven shall be suitable for continuous operation at temperatures to  $200^\circ\text{C}$ .

(d) Fuel and burner air shall conform to specifications.

(e) The percent of oxygen interference must be less than 3 percent.

(f) Premixed burner air:

(1) For Diesel engines, premixing a small amount of air with the HFID fuel prior to combustion within the HFID burner is not recommended as a means of improving oxygen interference (%O<sub>2</sub>I). However, this procedure may be used if the engine manufacturer demonstrates on each basic combustion system (i.e., 4 cycle DI, 2 cycle DI, 4 cycle precup, etc.) that an HFID using this procedure produces comparable results to an HFID not using this procedure. These data must be submitted to the Administrator for his approval prior to testing.

#### **§ 1065.135 NO<sub>x</sub> analyzers.**

This section describes the requirements for chemiluminescent detectors (CLD) used to measure NO<sub>x</sub>. Good engineering practice may require the use of other detectors.

(a) A CLD must meet the following requirements:

- (1) Make sure your CLD meets the accuracy and precision specifications in ISO 8178–1 (incorporated by reference in § 1065.1010).
  - (2) The NO to NO<sub>2</sub> converter must have an efficiency of at least 90 percent.
  - (3) Use an overflow sampling system for continuous CLDs. (In an overflow system excess zero gas or span gas spills out of the probe when you are doing zero or span checks.)
  - (4) You do not need a heated CLD to test spark-ignition engines.
- (b) Using CLDs is generally acceptable even though they measure only NO and NO<sub>2</sub>, since conventional engines do not emit significant amounts of other NO<sub>x</sub> species.

#### **§ 1065.140 CO and CO<sub>2</sub> analyzers.**

This section describes the requirements for non-dispersive infrared absorption detectors (NDIR) to measure CO and CO<sub>2</sub>.

- (a) The NDIR must meet the applicable accuracy and precision specifications of ISO 8178–1 (incorporated by reference in § 1065.1010).
- (b) The NDIR must meet the applicable quench and interference requirements of ISO 8178–1 (incorporated by reference in § 1065.1010).

#### **§ 1065.145 Smoke meters.**

##### Specifications — opacimeters

##### General

Smoke tests require the use of a smoke measurement and data processing system which includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

- a full-flow or a partial-flow opacimeter meeting the specifications of this clause.
- a data processing unit capable of performing the functions required
- a printer and/or electronic storage medium to record and output the required smoke values

##### Linearity

Linearity is defined as the difference between the value measured by the opacimeter and the reference value of the calibrating device. The linearity shall not exceed 2 % opacity.

##### Zero drift

The zero drift over either a one hour period or the duration of the test – whichever is the lesser – shall not exceed 1 % opacity.

##### Opacimeter display and range

For display in both opacity and light absorption coefficient the opacimeter shall have a measuring range appropriate for accurately measuring the smoke of the engine being tested. The resolution shall be at least 0.1 % of full scale.

The optical path length selected for the smoke instrument shall be suitable for the smoke levels being measured in order to minimize errors in calibrations, measurements and calculations.

##### Instrument response time

The physical response time of the opacimeter shall not exceed 0.2 s, and the electrical response time of the opacimeter shall not exceed 0.05 s.

##### Sampling requirements for partial-flow opacimeters

The sampling conditions shall conform to the requirements.

Light source

The light source shall conform to the requirements.

Neutral density filters

Any neutral density filters used for calibrating and checking opacimeters must be known to an accuracy of 1 % opacity and the filter's nominal value must be checked for accuracy at least yearly using a reference traceable to a national or International Standard.

NOTE Neutral density filters are precision devices and can easily be damaged during use. Handling should be minimized and, when required, should be done with care to avoid scratching or soiling of the filter.

Accuracy

The calibration of all measuring instruments shall be traceable to International Standards (or national standards if no International Standards exist).

~~{Reserved}~~

#### **§ 1065.150 Flow meters.**

(a) Flow meters must have accuracy and precision of  $\pm 2$  percent of point or better and be traceable to NIST standards.

(b) You may correct flow measurements for temperature or pressure, if your temperature and pressure measurements have accuracy and precision of  $\pm 2$  percent of point or better (absolute).

#### **§ 1065.155 Temperature and pressure sensors.**

(a) Except where we specify otherwise in this part, must meet the applicable accuracy and precision specifications of

ISO 8178-1 (incorporated by reference in § 1065.1010).

(b) Use good engineering judgment to design and operate your temperature and pressure measuring systems to minimize delays in response time and avoid hysteresis.

#### **§ 1065.160 Particulate mass measurement equipment and performance**

(a) Ambient conditions for filter stabilization and weighing. (1) Temperature and humidity. (i) The filter stabilization environment shall be maintained at  $22\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$  and a dewpoint of  $9.5\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ . Dewpoint shall be measured with an instrument that exhibits an accuracy of at least  $\pm 0.25\text{ }^{\circ}\text{C}$  NIST traceable as stated by the instrument manufacturer. Temperature shall be measured with an instrument that exhibits an accuracy of at least  $\pm 0.2\text{ }^{\circ}\text{C}$  or better.

(ii) The immediate microbalance workstation environment shall be maintained at  $22\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$  and a dewpoint of  $9.5\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ . If the microbalance workstation environment freely circulates with the filter stabilization environment, and this entire environment meets  $22\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$  and a dewpoint of  $9.5\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ , then there is no requirement to measure temperature and dewpoint at the microbalance separate from the filter stabilization location. Otherwise, temperature at the microbalance workstation shall be measured with an instrument that exhibits an accuracy of at least  $\pm 0.2\text{ }^{\circ}\text{C}$  or better, and dewpoint shall be measured with an instrument that exhibits an accuracy of at least  $\pm 0.25\text{ }^{\circ}\text{C}$  NIST traceable as stated by the instrument manufacturer.

(2) Cleanliness. (i) The microbalance and filter stabilization environments shall be free of ambient contaminants (such as dust or other aerosols) that could settle on the particulate filters. It is recommended that these environments be built to conform with the Class Six (6) specification (or cleaner) as determined by ISO 14644-1 incorporated by reference at §1065.1010. An alternative recommendation would be to equilibrate and/or weigh the filters within a separate, smaller, particle-free, temperature and humidity-controlled chamber (i.e., "glove box").

(ii) Reference filters shall be used to monitor for gross particle contamination. It is required that at least two unused reference filters remain in the filter stabilization environment at all times in partially covered glass Petri dishes, as in paragraph (c) (1) of this section. These reference filters shall be placed in the filter stabilization environment. The reference filters shall be weighed within 2 hours of, but preferably at the same time as, the sample filters. The reference filters shall be changed at least once a month, but never while any sample filters are between their tare weight (pre-sampling) and gross weight (post-sampling) measurements. The reference filters shall be the same size and material as the sample filters.

(3) Quality control of ambient conditions. (i) If, before the start of a weighing session, the temperature or dewpoint of the filter stabilization environment are not within specifications, then filters must remain in the environment for at least 30 minutes (60 minutes for engines with particulate mass standards greater than 0.01 g/hp-hr (0.0134 g/kw-hr)) after conditions are corrected. If the filter stabilization environment changes during a weighing session such that the specifications are no longer met, the weighing session shall be suspended until the environment has returned to within specifications for at least 30 minutes (60 minutes for engines with particulate mass standards greater than 0.01 g/hp-hr (0.0134 g/kw-hr)), the reference filters shall be reweighed and the criteria in paragraph (a)(3)(ii) of this section shall apply. Note that temperature and dewpoint shall be sampled once per second, and an unweighted 5-minute moving average of this data shall be calculated once per second. This moving average shall be used to determine the environment temperature and dewpoint for the purpose of determining whether or not the environment is within specifications.

(ii) If the average change in weight of the reference filters is more than 10 micrograms (after correcting for buoyancy as described in paragraph (c)(3) of this section), then all filters in the process of stabilization shall be discarded and all data collected with respect to the discarded filters shall be considered void. Note that more than 2 reference filters may be used to achieve a more robust average of the change in weight of the reference filters.

(b) Microbalance specifications. The microbalance used to determine the weights of all filters shall have a precision (standard deviation) of at least  $\pm 0.25$  micrograms or better for repeated weighing of a calibration weight, a precision of at least  $\pm 2.5$  micrograms or better for repeated weighing of a clean filter, and a readability equal to or less than 0.1 micrograms. It is recommended that the microbalance be installed on a vibration isolation platform to isolate the microbalance's load cell from external vibration. It is also recommended that the microbalance should be shielded from convective airflow by means of an electrically grounded static dissipative draft shield. Microbalance manufacturer specifications for all preventive maintenance, periodic certification, calibration, and re-zeroing shall be followed. All certification and calibration procedures shall be NIST traceable, or traceable to an equivalent national standard.

## **Subpart C—Test Fuels and Analytical Gases**

### **§ 1065.201 General requirements for test fuels.**

(a) For all emission tests, use test fuels meeting the specifications in this subpart, unless the standard-setting part directs otherwise. For any service accumulation on a test engine, if we do not specify a fuel, use the specified test fuel or a fuel typical of what you would expect the engine to use in service.

(b) We may require you to test the engine with each type of fuel it can use (for example, gasoline and natural gas).

(c) If you will produce engines that can run on a type of fuel (or mixture of fuels) that we do not specify in this subpart, we will allow you to test with fuel representing commercially available fuels of that type. However, we must approve your fuel's specifications before you may use it for emission testing.

(d) You may use a test fuel other than those we specify in this subpart if you do all of the following:

(1) Show that it is commercially available.

(2) Show that your engines will use only the designated fuel in service.

(3) Show that operating the engines on the fuel we specify would increase emissions or decrease durability.

(4) Get our written approval before you start testing.

(e) We may allow you to use other test fuels (for example, California Phase 2 gasoline) if they do not affect the demonstration of compliance.

### **§ 1065.205 Test fuel specifications for distillate diesel fuel. ~~{Reserved}~~**

The following petroleum fuel specifications are for exhaust emissions testing of diesel-fueled vehicles that incorporate sulfur-sensitive technologies for which the manufacturer clearly recommends to the ultimate purchaser in the owner's manual that the vehicle should use fuel with no higher than 15 ppm sulfur. Such fuel must meet the following specifications or substantially equivalent specifications approved by the Administrator. The grade of petroleum diesel fuel recommended by the engine manufacturer, commercially designated as ``Type 2-D'' grade diesel, must be used:

<u>Item</u>	<u>ASTM test</u>	<u>Type 2-D</u>
<u>Cetane Number</u>	<u>D613</u>	<u>40-50</u>
<u>Cetane Index</u>	<u>D976</u>	<u>40-50</u>
<u>Distillation range</u>		
<u>(A) IBP</u>	<u>D86</u>	<u>340-400 °F</u> <u>171.1-204.4 °C</u>
<u>(B) 10 pct. point</u>	<u>D86</u>	<u>400-460 °F</u> <u>204.4-237.8 °C</u>
<u>(C) 50 pct. point</u>	<u>D86</u>	<u>470-540 °F</u> <u>243.3-282.2 °C</u>
<u>(D) 90 pct. point</u>	<u>D86</u>	<u>560-630 °F</u> <u>293.3-332.2 °C</u>
<u>(E) EP</u>	<u>D86</u>	<u>610-690 °F</u> <u>321.1-365.6 °C</u>
<u>Gravity</u>	<u>D287</u>	<u>32-37 °API</u>
<u>Total sulfur</u>	<u>D2622</u>	<u>7-15 ppm</u>
<u>Aromatics, remainder shall be paraffins, naphthenes, and olefins</u>	<u>D5186</u>	<u>Minimum, 10 percent (%)</u>
<u>Flashpoint</u>	<u>D93</u>	<u>Minimum, 130 °F</u> <u>54.4 °C</u>
<u>Viscosity</u>	<u>D445</u>	<u>2.0-3.2 Cst</u>

The following petroleum fuel specifications are for service accumulation of diesel-fueled vehicles that incorporate sulfur-sensitive technologies for which the manufacturer clearly recommends to the ultimate purchaser in the owner's manual that the vehicle should use fuel with no higher than 15 ppm sulfur. Such fuel must meet the following specifications or substantially equivalent specifications approved by the Administrator. The grade of petroleum diesel fuel recommended by the engine manufacturer, commercially designated as "Type 2-D" grade diesel, must be used:

<u>Item</u>	<u>ASTM test</u>	<u>Type 2-D</u>
<u>Cetane Number</u>	<u>D613</u>	<u>38-48</u>
<u>Cetane Index</u>	<u>D976</u>	<u>Minimum, 40</u>
<u>Distillation range</u>		
<u>90 pct. point</u>	<u>D86</u>	<u>560-630 °F</u> <u>293.3-332.2 °C</u>
<u>Gravity</u>	<u>D287</u>	<u>30-39 °API</u>
<u>Total sulfur</u>	<u>D2622</u>	<u>7-15 ppm</u>
<u>Flashpoint</u>	<u>D93</u>	<u>Minimum, 130 °F</u> <u>54.4 °C</u>
<u>Viscosity</u>	<u>D445</u>	<u>1.5-4.5 Cst</u>

- (1) Use diesel fuels for testing which are clean and bright, with pour and cloud points adequate for operability. The diesel fuel may contain nonmetallic additives as follows: Cetane improver, metal deactivator, antioxidant, dehazer, antirust, pour depressant, dye, dispersant, and biocide.
- (2) Use petroleum fuel meeting the specifications in tables of this subpart, or substantially equivalent specifications approved by the Administrator, for exhaust emission testing. The grade of diesel fuel used must be commercially designated as "Type 2-D" grade diesel fuel and recommended by the engine manufacturer.
- (3) Testing of Tier 1 engines rated under 37 kW or Tier 2 engines rated at or above 37 kW that is conducted by the Administrator shall be performed using test fuels that meet the specifications in this subpart and that have a sulfur content no higher than 0.20 weight percent.
- (c) Other fuels may be used for testing provided they meet the following qualifications:
- (1) They are commercially available;

(2) Information acceptable to the Administrator is provided to show that only the designated fuel would be used in customer service;

(3) Use of a fuel listed under paragraph (b) of this section would have a detrimental effect on emissions or durability; and

(4) Fuel specifications are approved in writing by the Administrator prior to the start of testing.

(d) Report the specification range of the fuel to be used.

**§ 1065.210 Test fuel specifications for gasoline.**

Gasoline used as a test fuel must meet the following specifications:

(a) Unless the standard-setting part requires testing with fuel appropriate for low temperatures, use gasoline test fuels meeting the specifications in the following table:

TABLE 1 OF § 1065.210.—GENERAL TEST-FUEL SPECIFICATIONS FOR GASOLINE

Item	Procedure <sup>1</sup>	Value <sup>1</sup>
Distillation Range:		
1. Initial boiling point, °C .....	ASTM D 86–01	23.9–35.0 <sup>2</sup>
2. 10% point, °C .....	ASTM D 86–01	48.9–57.2
3.50% point, °C .....	ASTM D 86–01	93.3–110.0
4. 90% point, °C .....	ASTM D 86–01	148.9–162.8
5. End point, °C (maximum) .....	ASTM D 86–01	212.8.
Hydrocarbon composition:		
1. Olefins, volume % .....	ASTM D 1319–02	10 maximum
2. Aromatics, volume % .....	ASTM D 1319–02	35 maximum
3. Saturates .....	ASTM D 1319–02	Remainder
Lead (organic), g/liter .....	ASTM D 3237–97	0.013 maximum
Phosphorous, g/liter .....	ASTM D 3231–02	0.0013 maximum

TABLE 1 OF § 1065.210.—GENERAL TEST-FUEL SPECIFICATIONS FOR GASOLINE—Continued

Item	Procedure <sup>1</sup>	Value <sup>1</sup>
Sulfur, weight % .....	ASTM D 1266–98	0.008 maximum
Volatility (Reid Vapor Pressure), kPa .....	ASTM D 323–99a	60.0 to 63.4, <sup>2,3</sup>

(b) If the standard-setting part requires testing with fuel appropriate for low temperatures, use gasoline test fuels meeting the specifications in the following table:

TABLE 2 OF § 1065.210.—LOW-TEMPERATURE TEST-FUEL SPECIFICATIONS FOR GASOLINE

Item	Procedure <sup>1</sup>	Value <sup>1</sup>
Distillation Range:		
1. Initial boiling point, °C .....	ASTM D 86–01	24.4–35.6.
2. 10% point, °C .....	ASTM D 86–01	36.7–47.8.
3. 50% point, °C .....	ASTM D 86–01	81.7–101.1.
4. 90% point, °C .....	ASTM D 86–01	157.8–174.4.
5. End point, °C (maximum) .....	ASTM D 86–01	211.7.
Hydrocarbon composition:		
1. Olefins, volume % .....	ASTM D 1319–02	17.5 maximum.
2. Aromatics, volume % .....	ASTM D 1319–02	30.4 maximum.
3. Saturates .....	ASTM D 1319–02	Remainder.
Lead (organic), g/liter .....	ASTM D 3237–97	0.013 maximum.
Phosphorous, g/liter .....	ASTM D 3231–02	0.005 maximum.
Sulfur, weight % .....	ASTM D 1266–98	0.08 maximum.
Volatility (Reid Vapor Pressure), kPa .....	ASTM D 323–99a	11.2–11.8 psi.

<sup>1</sup>All ASTM standards are incorporated by reference in § 1065.1010.

(c) Use gasoline test fuel with octane values that represent commercially available fuels for the appropriate application.

#### § 1065.215 Test fuel specifications for natural gas.

(a) Natural gas used as a test fuel must meet the specifications in the following table:

TABLE 1 OF § 1065.215.—TEST-FUEL SPECIFICATIONS FOR NATURAL GAS

Item	Procedure <sup>1</sup>	Value (mole percent)
1. Methane .....	ASTM D 1945–96	87.0 minimum.
2. Ethane .....	ASTM D 1945–96	5.5 maximum.
3. Propane .....	ASTM D 1945–96	1.2 maximum.
4. Butane .....	ASTM D 1945–96	0.35 maximum.
5. Pentane .....	ASTM D 1945–96	0.13 maximum.
6. C6 and higher .....	ASTM D 1945–96	0.1 maximum.
7. Oxygen .....	ASTM D 1945–96	1.0 maximum.
8. Inert gases (sum of CO <sub>2</sub> and N <sub>2</sub> ) .....	ASTM D 1945–96	5.1 maximum.

<sup>1</sup>All ASTM standards are incorporated by reference in § 1065.1010.

(b) At ambient conditions, the fuel must have a distinctive odor detectable down to a concentration in air of not more than one-fifth of the lower flammability limit.

#### § 1065.220 Test fuel specifications for liquefied petroleum gas.

(a) Liquefied petroleum gas used as a test fuel must meet the specifications in the following table:

TABLE 1 OF § 1065.215.—TEST-FUEL SPECIFICATIONS FOR NATURAL GAS

Item	Procedure <sup>1</sup>	Value (mole percent)
1. Methane .....	ASTM D 1945–96	87.0 minimum.
2. Ethane .....	ASTM D 1945–96	5.5 maximum.
3. Propane .....	ASTM D 1945–96	1.2 maximum.
4. Butane .....	ASTM D 1945–96	0.35 maximum.
5. Pentane .....	ASTM D 1945–96	0.13 maximum.
6. C6 and higher .....	ASTM D 1945–96	0.1 maximum.
7. Oxygen .....	ASTM D 1945–96	1.0 maximum.
8. Inert gases (sum of CO <sub>2</sub> and N <sub>2</sub> ) .....	ASTM D 1945–96	5.1 maximum.

<sup>1</sup>All ASTM standards are incorporated by reference in § 1065.1010.

(b) At ambient conditions, the fuel must have a distinctive odor detectable down to a concentration in air of not over one-fifth of the lower flammability limit.

**§ 1065.240 Lubricating oils.**

Lubricating oils you use to comply with this part must be commercially available and represent the oil that will be used with your in-use engines.

**§ 1065.250 Analytical gases.**

Analytical gases that you use to comply with this part must meet the accuracy and purity specifications of this section. You must record the expiration date specified by the gas supplier and may not use any gas after the expiration date.

(a) *Pure gases.* Use the “pure gases” shown in the following table:

TABLE 1 OF § 1065.250.—CONCENTRATION LIMITS FOR PURE GASES

Gas type	Maximum contaminant concentrations				Oxygen content
	Organic carbon	Carbon monoxide	Carbon dioxide	Nitric oxide (NO)	
Purified Nitrogen .....	1 ppmC .....	1 ppm .....	400 ppm .....	0.1 ppm .....	NA.
Purified Oxygen .....	NA .....	NA .....	NA .....	NA .....	99.5–100.0%.
Purified Synthetic Air, or Zero-Grade Air.	1 ppmC .....	1 ppm .....	400 ppm .....	0.1 ppm .....	18–21%.

or

The required purity of the gases is defined by the contamination limits given below. The following gases shall be available for operation:

Purified nitrogen (contamination  $\delta$  1 ppmC,  $\delta$  1 ppmCO,  $\delta$  400 ppmCO<sub>2</sub>,  $\delta$  0.1 ppmNO)

Purified oxygen (Purity > 99.5 % vol O<sub>2</sub>)

The shelf life of all calibration gases must be respected.

The expiry date of the calibration gases stated by the manufacturer shall be recorded.

(b) *Fuel for flame ionization detectors.*

Use a hydrogen-helium mixture as the fuel. Make sure the mixture contains  $40 \pm 2$  percent hydrogen and no more than

1 ppmC of organic carbon or 400 ppm of CO<sub>2</sub>.

Or

Hydrogen-helium mixture ( $40 \pm 2$  % hydrogen, balance helium) Contamination  $\delta$  1 ppmC,  $\delta$  400 ppm CO<sub>2</sub>)

Purified synthetic air (contamination  $\delta$  1 ppmC,  $\delta$  1 ppmCO,  $\delta$  400 ppmCO<sub>2</sub>,  $\delta$  0.1 ppm NO (oxygen content 18 % –21 % vol.)

(c) *Calibration and span gases.* Apply the following provisions to calibration and span gases:

(1) Use the following gas mixtures, as applicable, for calibrating and spanning your analytical instruments:

(i) Propane in purified synthetic air.

You may ask us to allow you to use propane in purified nitrogen for high concentrations of propane.

(ii) CO in purified nitrogen.

(iii) NO and NO<sub>2</sub> in purified nitrogen (the amount of NO<sub>2</sub> in this calibration gas must not exceed 5 percent of the NO content).

(iv) Oxygen in purified nitrogen.

(v) CO<sub>2</sub> in purified nitrogen.

(vi) Methane in purified synthetic air.

(2) The calibration gases in paragraph (c)(1) of this section must be traceable to within one percent of NIST gas standards or other gas standards we have approved. Span gases in paragraph (c)(1) of this section must be accurate to within two percent of true concentration, where true concentration refers to NIST gas standards, or other gas standards we have approved. Record concentrations of calibration gas as volume percent or volume ppm.

(3) You may use gases for species other than those in paragraph (c)(1) of this section (such as methanol in air gases used to determine response factors), as long as they meet the following criteria:

- (i) They are traceable to within  $\pm 2$  percent of NIST gas standards or other standards we have approved.
- (ii) They remain within  $\pm 2$  percent of the labeled concentration. Show this by measuring quarterly with a precision of

$\pm 2$  percent (two standard deviations) or by using another method we approve. You may take multiple measurements. If

the true concentration of the gas changes by more than two percent, but less than ten percent, you may relabel the gas with the new concentration.

(4) You may generate calibration and span gases using precision blending devices (gas dividers) to dilute gases with purified nitrogen or with purified synthetic air. Make sure the mixing device produces a concentration of blended calibration gases that is accurate to within  $\pm 1.5$  percent. To do so, you must know the concentration of primary gases used for blending to an accuracy of at least  $\pm 1$  percent, traceable to NIST gas standards or other gas standards we have approved. For each calibration incorporating a blending device, verify the blending accuracy between 15 and 50 percent of full scale. You may optionally check the blending device with an instrument that is linear by nature (for example, using NO gas with a CLD). Adjust the instrument's span value with the span gas connected directly to it. Check the blending device at the used settings to ensure that the difference between nominal values and measured concentrations at each point stays within  $\pm 0.5$  percent of the nominal value.

(d) *Oxygen interference gases.* Gases to check oxygen interference are mixtures of oxygen, nitrogen, and propane. The oxygen concentration must be 20–22 percent and the propane concentration must be 50–90 percent of the maximum value in the most typically used FID range. Independently measure the concentration of total hydrocarbons plus impurities by chromatographic analysis or by dynamic blending.

## Subpart D—Analyzer and Equipment Calibrations

### § 1065.301 Overview.

Calibrate all analyzers and equipment at least annually, but make the actual frequency consistent with good engineering judgment. We may establish other guidelines as appropriate. Calibrate following specifications in one of three sources:

- (a) Recommendations from the manufacturer of the analyzers or equipment.
- (b) 40 CFR part 86, subpart F or subpart N.

Gases other than the one being analysed can interfere with the reading in several ways. Positive interference occurs in NDIR and PMD instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the radiation. The interference checks shall be performed prior to an analyser's initial use and after major service intervals, but at least once per year.

This section describes the initial and periodic calibration of the chemiluminescent oxides of nitrogen analyzer.

(a) Prior to introduction into service and at least monthly thereafter, the chemiluminescent oxides of nitrogen analyzer must be checked for NO<sub>2</sub> to NO converter efficiency.

(1) Follow good engineering practices for instrument start-up and operation. Adjust the analyzer to optimize performance.

(2) Zero the oxides of nitrogen analyzer with zero-grade nitrogen.

(3) Connect the outlet of the NO<sub>x</sub> generator to the sample inlet of the oxides of nitrogen analyzer, which has been set to the most common operating range.

(4) Introduce into the NO<sub>x</sub> generator-analyzer system an NO-in-nitrogen (N<sub>2</sub>) mixture with an NO concentration equal to approximately 80 percent of the most common operating range. The NO<sub>2</sub> content of the gas mixture shall be less than 5 percent of the NO concentration.

(5) With the oxides of nitrogen analyzer in the NO mode, record the concentration of NO indicated by the analyzer.

(6) Turn on the NOx generator O2 supply and adjust the O2 flow rate so that the NO indicated by the analyzer is about 10 percent less than indicated in paragraph (a)(5) of this section. Record the concentration of NO in this NO + O2 mixture.

(7) Switch the NOx generator to the generation mode and adjust the generation rate so that the NO measured by the analyzer is 20 percent of that measured in paragraph (a)(5) of this section. There must be at least 10 percent unreacted NO at this point. Record the concentration of residual NO.

(8) Switch the oxides of nitrogen analyzer to the NOx mode and measure total NOx. Record this value.

(9) Switch off the NOx generator but maintain gas flow through the system. The oxides of nitrogen analyzer will indicate the NOx in the NO + O2 mixture. Record this value.

(10) Turn off the NOx generator O2 supply. The analyzer will now indicate the NOx in the original NO-in-N2 mixture. This value should be no more than 5 percent above the value indicated in paragraph (a)(4) of this section.

(11) Calculate the efficiency of the NOx converter by substituting the concentrations obtained into the following equation:

$$\text{Percent - efficiency} = \left( 1 + \frac{a - b}{c - d} \right) \times 100$$

$$\text{Percent - efficiency} = \left( 1 + \frac{a - b}{c - d} \right) \times 100$$

Where:

a = concentration obtained in paragraph (a)(8) of this section.  
b = concentration obtained in paragraph (a)(9) of this section.  
c = concentration obtained in paragraph (a)(6) of this section.  
d = concentration obtained in paragraph (a)(7) of this section.

(12) If converter efficiency is not greater than 90 percent, repair the analyzer. The repaired analyzer must achieve a converter efficiency greater than 90 percent before the analyzer may be used.

(b) Accuracy. The accuracy at the minimum limit of the NOx analyzer is defined in §86.1338-2007. In general the analyzer's minimum limit shall be the lowest concentration within a given range, in which it has an accuracy of ±2 percent of point.

(c) Initial and periodic calibration. Prior to its introduction into service and monthly thereafter, the chemiluminescent oxides of nitrogen analyzer shall be calibrated on all normally used instrument ranges. Use the same flow rate as when analyzing samples. Proceed as follows:

(1) Adjust analyzer to optimize performance.

(2) Zero the oxides of nitrogen analyzer with zero-grade nitrogen (N2).

(3) (i) Calibrate all operating ranges with a minimum of 9 NO-in-N2 calibration gases (e.g., 10, 20, 30, 40, 50, 60, 70, 80, and 90 percent of that range) and one zero-grade N2 gas. Sound engineering judgment shall dictate appropriate spacing and weighting of the calibration points.

(ii) For each range calibrated, if all deviations from a least-squares best-fit straight line are within ±2 percent of the value at each non-zero data point and within ±0.3 percent of full scale on the zero data point, then concentration values may be calculated using the linear calibration equation for that range. If the specified deviations are exceeded for ranges that have a minimum limit of 1 ppm or greater, then the best-fit non-linear equation that represents the data within these deviations may be used to determine concentration values. For ranges that have a minimum limit less than

1 ppm, only a linear or second order non-linear equation that represents the data within these deviations, may be used to determine concentration values.

(d) Chemiluminescent NO<sub>x</sub> analyzer interference check (i.e., quench check). Prior to its introduction into service and at least once per year thereafter, the quench check described in this section shall be performed on CLD NO<sub>x</sub> analyzers. CO<sub>2</sub> and water vapor interfere with the response of a CLD by collisional quenching. The combined quench effect at their highest expected concentrations shall not exceed 2 percent. For an integrated or bag NO<sub>x</sub> analyzer, compensation algorithms that utilize other integrated or bag measurements of other gases, may be used to meet the interference check specified in this subparagraph (d). Using sound engineering judgment, expected bag measurements of other gases may be simulated in such algorithms during the analyzer interference check in this subparagraph (d). For a continuous NO<sub>x</sub> analyzer, similar algorithms may be used if approved under 1306-07.

(1) CO<sub>2</sub> quench check procedure: (i) For the procedure described in this paragraph, variations are acceptable provided that they produce equivalent %CO<sub>2quench</sub> results. Connect a pressure-regulated CO<sub>2</sub> span gas to one of the inlets of a three-way valve. Its CO<sub>2</sub> concentration should be approximately twice the maximum CO<sub>2</sub> concentration expected during testing. The valve must be leak-free, and its wetted parts must be made of a stainless steel or other inert material. Connect a pressure-regulated zero-grade N<sub>2</sub> gas to the other inlet of the three-way valve. Connect the single outlet of the valve to the balance-gas port of a properly operating gas divider. Connect a pressure-regulated NO span gas, which has approximately twice the typical NO concentration expected during testing, to the span-port of the gas divider. Configure the gas divider such that nearly equal amounts of the span gas and balance gas are blended with each other. Viscosity corrections shall be applied appropriately to ensure correct mass flow determinations.

(ii) With the CO<sub>2</sub> flowing to the balance port and the NO flowing to the span port, measure a stable CO<sub>2</sub> concentration from the gas divider's outlet with a properly calibrated NDIR analyzer. Record this concentration in percent (%); this is "%CO<sub>2</sub>". This value will be used in the water vapor quench check calculations that are detailed in the following section. After the %CO<sub>2</sub> measurement, measure the NO concentration at the gas divider outlet with the CLD analyzer in the NO mode. Record this concentration in ppm; this is "NO<sub>CO2</sub>". Then switch the three-way valve such that 100 percent N<sub>2</sub> flows to the balance port inlet. Monitor the CO<sub>2</sub> concentration of the gas divider's outlet until its concentration stabilizes at zero. Then measure the stable NO concentration from the gas divider's outlet. Record this value in ppm; this is "NO<sub>N2</sub>". Calculate %CO<sub>2quench</sub> as follows:

$$\%CO_{2quench} = (1.00 - (NO_{CO2} / NO_{N2})) \times 100$$

(2) Water vapor quench check procedure:

(i) For all dry CLD analyzers it must be demonstrated that for the highest expected water vapor concentration (i.e., "%H<sub>2</sub>O<sub>exp</sub>" as calculated later in this section), the water removal technique maintains CLD humidity at less than or equal to 5 g<sub>water</sub>/kg<sub>dry air</sub> (or about 0.008 percent H<sub>2</sub>O), which is 100% RH at 3.9 °C and 101.3 kPa. This humidity specification is also equivalent to about 25% RH at 25 °C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD. Humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow out of the dehumidifier.

(ii) For all "wet" CLD analyzers the following water vapor quench check procedure shall be followed. Measure an NO span gas, which has 90% to 100% of the typical NO expected during testing, using the CLD in the NO mode. Record this concentration in ppm; this is "NO<sub>dry</sub>". Then bubble the same NO span gas through distilled water in a sealed vessel at 25 °C ±10 °C. This temperature specification imposed to ensure that the H<sub>2</sub>O<sub>vol</sub> calculation (refer to (iii) of this section) returns an accurate result. To prevent subsequent condensation, this temperature must also be less than any temperature that the wetted sample will experience between the sealed vessel's outlet and the CLD. Record the vessel's water temperature in °C; this is "T<sub>sat</sub>". Record the vessel's absolute pressure in kPa; this is "P<sub>sat</sub>". Measure the wetted span gas with the CLD, and record this value in ppm; this is "NO<sub>wet</sub>".

(iii) Calculations for water quench must consider dilution of the NO span gas with water vapor and scaling of the water vapor concentration to that expected during testing.

(A) Calculate the volume fraction of water vapor in the wetted span gas, as  $H_{2O_{vol}} = (\exp(3.69 - (81.28/T_{sat})) + 1.61) / P_{sat}$ . This calculation approximates some of the thermodynamic properties of water based on the "1995 Formulation for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use", issued by The International Association for the Properties of Water and Steam (IAPWS).

However, this approximation should only be used as prescribed in this section because it is an exponential fit that is accurate for data at 25 °C ±10 °C. Then, assuming a diesel fuel atomic hydrogen to carbon ratio of 1.8, and an intake and dilution air humidity of 75 grains (10.71 g<sub>water</sub>/kg<sub>dry air</sub>, or 54.13 percent RH at 25 °C and 101.3 kPa).

(B) Calculate the maximum percent water vapor expected during testing; as  $\%H_2O_{exp} = (0.90 \times \%CO_2) + 1.69$ .  $\%CO_2$  is the value measured during the  $\%CO_2$  quench check.

(C) Calculate the expected wet concentration of NO in ppm; as  $NO_{exp} = NO_{dry} \times (1.00 - H_2O_{vol})$

(iv) Calculate the percent water vapor quench as:

$\%H_2O_{quench} = ((NO_{exp} - NO_{wet}) / NO_{exp}) \times (\%H_2O_{exp} / H_2O_{vol})$

(3) Add the  $\%CO_{2quench}$  and the  $\%H_2O_{quench}$  values. Their sum may not exceed the limit set in paragraph (d). If their sum is greater than this limit, then the CLD instrument may not be used to perform testing unless it is repaired. The analyzer must be shown to pass this quench check after the repair before it may be used for testing.

~~(e) 40 CFR part 90, subparts D and E, as applicable.~~

#### **§ 1065.305 International calibration standards.**

(a) You may ask to use international standards for calibration.

(b) You need not ask for approval to use standards that have been shown to be traceable to NIST standards.

#### **§ 1065.310 CVS calibration.**

Gas meter or flow instrumentation calibration; particulate, methanol, and formaldehyde measurement.

(a) Sampling for particulate, methanol and formaldehyde emissions requires the use of gas meters or flow instrumentation to determine flow through the particulate filters, methanol impingers and formaldehyde impingers. These instruments shall receive initial and periodic calibrations as follows:

(1)(i) Install a calibration device in series with the instrument. A critical flow orifice, a bellmouth nozzle, or a laminar flow element or an NBS traceable flow calibration device is required as the standard device.

(ii) The flow system should be checked for leaks between the calibration and sampling meters, including any pumps that may be part of the system, using good engineering practice.

(2) Flow air through the calibration system at the sample flow rate used for particulate, methanol, and formaldehyde testing and at the backpressure which occurs during the sample test.

(3) When the temperature and pressure in the system have stabilized, measure the indicated gas volume over a time period of at least five minutes or until a gas volume of at least ±1 percent accuracy can be determined by the standard device. Record the stabilized air temperature and pressure upstream of the instrument and as required for the standard device.

(4) Calculate air flow at standard conditions as measured by both the standard device and the instrument(s). (Standard conditions are defined as 68 °F (20 °C) and 29.92 in Hg (101.3 kPa).)

(5) Repeat the procedures of paragraphs (a) (2) through (4) of this section using at least two flow rates which bracket the typical operating range.

(6) If the air flow at standard conditions measured by the instrument differs by ±1.0 percent of the maximum operating range or ±2.0 percent of the point (whichever is smaller), then a correction shall be made by either of the following two methods:

(i) Mechanically adjust the instrument so that it agrees with the calibration measurement at the specified flow rates using the criteria of paragraph (a)(6) of this section, or

(ii) Develop a continuous best fit calibration curve for the instrument (as a function of the calibration device flow measurement) from the calibration points to determine corrected flow. The points on the calibration curve relative to the calibration device measurements must be within ±1.0 percent of the maximum operating range of ±2.0 percent of the point (whichever is smaller).

(7) For double dilution systems, the accuracy of the secondary dilution flow measurement device should be within ±1.0 percent of the total flow through the filter.

(b) Other systems. A bell prover may be used to calibrate the instrument if the procedure outlined in ANSI B109.1–1973 is used. Prior approval by the Administrator is not required to use the bell prover.

(a) The CVS is calibrated using an accurate flowmeter and restrictor valve. The flowmeter calibration shall be traceable to NIST or an equivalent national standard, and will serve as the reference value ("true" value) for the CVS calibration. (Note: In no case should an upstream screen or other restriction which can affect the flow be used ahead of the flowmeter unless calibrated throughout the flow range with such a device.) The CVS calibration procedures are designed for use of a "metering venturi" type flowmeter. Large radius or ASME flow nozzles are considered equivalent if traceable to NIST or an equivalent national standard. Other measurement systems may be used if shown to be equivalent under the test conditions in this section and traceable to NIST or an equivalent national standard. Measurements of the various flowmeter parameters are recorded and related to flow through the CVS. Procedures used by EPA for both PDP-CVS, SSV-CVS, and CFV-CVS are outlined below. (b) After the calibration curve has been obtained, verification of the entire system may be performed by injecting a known mass of gas into the system and comparing the mass indicated by the system to the true mass injected. An indicated error does not necessarily mean that the calibration is wrong, since other factors can influence the accuracy of the system (e.g., analyzer calibration, leaks, or HC hangup). A verification procedure is found in paragraph (e) of this section.

(c) Positive Displacement Pump (PDP) calibration. (1) The following calibration procedure outlines the equipment, the test configuration, and the various parameters which must be measured to establish the flow rate of the CVS pump.

(i) All the parameters related to the pump are simultaneously measured along with the parameters related to a calibration venturi that is connected in series with the pump.

(ii) The calculated flow rate,  $\text{ft}^3/\text{min}$  ( $\text{m}^3/\text{min}$ ), (at pump inlet absolute pressure and temperature) can then be plotted versus a flow slip parameter. (iii) The linear equation that relates the pump flow and a flow slip parameter is then determined.

(2) This calibration procedure is based on the measurement of the absolute values of the pump and flowmeter parameters that relate the flow rate at each point. Two conditions must be maintained to assure the accuracy and integrity of the calibration curve:

(i) The temperature stability must be maintained during calibration. (Flowmeters are sensitive to inlet temperature oscillations; this can cause the data points to be scattered. Gradual changes in temperature are acceptable as long as they occur over a period of several minutes.)

(ii) Eliminate leaks in all the connections and ducting between the calibration venturi and the CVS pump that are greater than 0.3% of the lowest flow point (highest restriction and lowest PDP speed point).

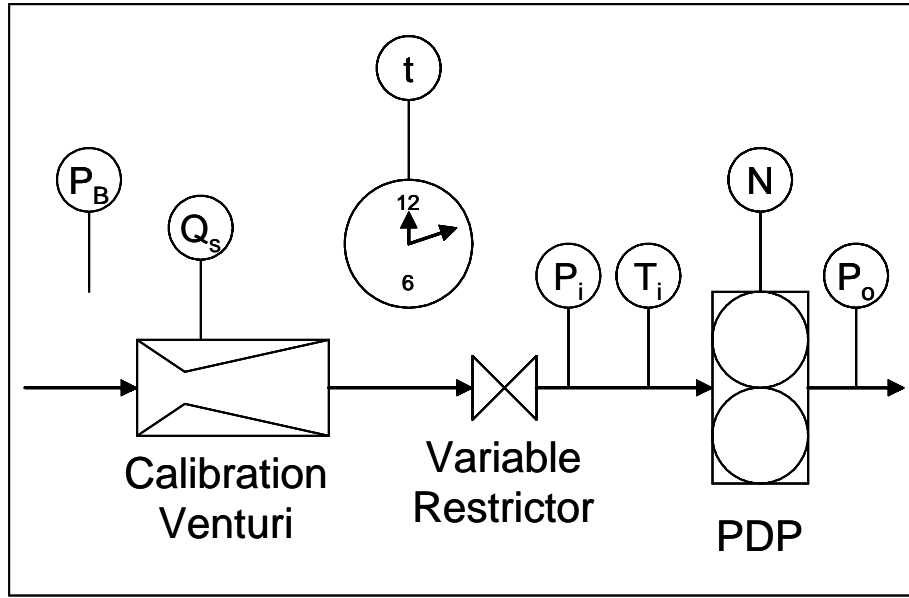
(3) During an exhaust emission test the measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

(4) Connect a system as shown in Figure N1319-1. Although particular types of equipment are shown, other configurations that yield equivalent results may be used. For the system indicated, the following measurement tolerances are required:

#### PDP Calibration Data Measurements and Tolerances

<u>Parameter</u>	<u>Symbol</u>	<u>Units</u>	<u>Tolerance</u>	
<u>Total, absolute atmospheric pressure (local, wet barometer)</u>	<u>P<sub>B</sub></u>	<u>in Hg@32°F (kPa)</u>	<u>± 0.01 in Hg@32°F (± 0.034 kPa)</u>	
<u>Air temperature at the inlet to the calibration venturi</u>	<u>—</u>	<u>°F (°C)</u>	<u>± 2.0 °F (1.1 °C)</u>	
<u>Static pressure drop between inlet to and throat of the calibration venturi</u>	<u>—</u>	<u>in Hg@32°F (kPa)</u>	<u>± 1% of minimum reading</u>	
<u>Static gage pressure at the inlet to the PDP (a negative value)</u>	<u>P<sub>i</sub></u>	<u>in Hg@32°F (kPa)</u>	<u>± 0.017 in Hg@32°F (± 0.057 kPa)</u>	
<u>Static gage pressure at the outlet of the PDP</u>	<u>P<sub>o</sub></u>	<u>in Hg@32°F (kPa)</u>	<u>± 0.017 in Hg@32°F (± 0.057 kPa)</u>	
<u>Temperature at PDP inlet</u>	<u>T<sub>i</sub></u>	<u>°F (°C)</u>	<u>± 2.0 °F (± 1.1 °C)</u>	
<u>Pump rpm during test period</u>	<u>N</u>	<u>rpm</u>	<u>± 0.5% of reading</u>	
<u>Elapsed time for test period</u>	<u>t</u>	<u>s</u>	<u>± 0.5 s</u>	

(5) After the system has been connected as shown schematically in Figure N1319-1, set the variable restrictor in the wide open position and run the CVS pump for 20 minutes. Record the calibration data.



**Figure N1319-1**

(6) Reset the restrictor valve to a more restricted condition in an increment of pump inlet depression that will yield a minimum of six data points for the total calibration. Allow the system to stabilize for 3 minutes and repeat the data acquisition.

(7) Data analysis:

(i) The standard air volume flow rate,  $Q_s$ , at each test point is calculated from the calibration venturi data. Use the method prescribed by the NIST traceable calibration, which should follow very similar flow equations to the SSV (e)(1)(i) – (iii). For a free standing calibration venturi its  $\beta = 0$  and  $P_{abs} = P_B$ . Standard pressure ( $P_{std}$ ) shall be 29.9213 in Hg@32°F, 101.325 kPa, and standard temperature ( $T_{std}$ ) shall be 68°F., 20° C, 527.67 °R, 293.15 K). In general, the absolute pressure is the measured pressure plus  $P_B$  and the absolute temperature is the measured temperature plus the 459.67 if the temperature is measured in °F (English units) or plus 273.15 if the temperature is measured in °C (metric units). (ii) The pump effective volumetric displacement,  $q_p$ , in  $\text{ft}^3/\text{rev}$  ( $\text{m}^3/\text{rev}$ ) is calculated based on  $Q_s$ , the pump inlet absolute temperature, and the pump inlet absolute pressure.

$$q_p = (Q_s / N) \times (P_{std} / P_{i, abs}) \times (T_{i, abs} / T_{std})$$

Where:

$P_{i, abs}$  = Absolute inlet pressure =  $P_i + P_B$

$T_{i, abs}$  = Absolute inlet temperature

$P_i$  = Static gage pressure at the inlet to the PDP

$T_i$  = Temperature at PDP inlet

(iii) A PDP flow slip parameter,  $S_p$ , is then calculated at each test point from the calibration data:

$$S_p = (1/N) \times \{(P_o - P_i) / (P_B + P_o)\}^{1/2} \quad \text{min/rev}$$

Where:

$P_o$  = Static gage pressure at the outlet of the PDP

(iv) A linear least squares regression of the calibration data is performed to generate the PDP calibration coefficients m, and b:

$$q_p = (m \times S_p) + b$$

where m is the flow slip calibration constant and b is the effective volumetric displacement with zero delta-p. (8) A CVS system that has multiple speeds must be calibrated on each speed used. The calibration curves generated for the ranges will be approximately parallel and the intercept values, b, will increase as the pump flow range decreases.

(9) If the calibration has been performed carefully, the calculated values from the equation will be within  $\pm 0.50\%$  of the measured value of  $q_p$ . Values of m will vary from one pump to another, but values of b for pumps of the same make, model and range should agree within  $\pm 3\%$  of each other. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m. Calibrations should be performed at pump start-up and after major maintenance to assure the stability of the pump slip rate. Analysis of mass injection data will also reflect pump slip stability.

(10) In use, the PDP actual volume flow rate,  $Q_{pdp}$  (equal to  $Q_s$ , the calibration venturi flow during calibration), is calculated as follows:

$$Q_{pdp} = q_p \times N \times (T_{std}/T_{i,abs}) \times (P_{i,abs}/P_{std})$$

Where,

$$q_p = (m \times S_p) + b$$

$P_{i,abs}$  = Absolute inlet pressure

$T_{i,abs}$  = Absolute inlet temperature

and

$$S_p = (1/N) \times \{(P_o - P_i) / (P_B + P_o)\}^{1/2}$$

as measured during use.

(d) Critical Flow Venturi (CFV) calibration. (1) Calibration of the CFV is based upon the flow equation for a critical flow venturi. CFV standard volume flow rate,  $Q_{cfv}$  is a function of inlet pressure, temperature, and dewpoint (i.e. molecular weight of the air flow). Dewpoint may be neglected if the dewpoint during CFV calibration is less than 52°F (11.1°C). However, such a CFV calibration shall only be valid for measured dilution air dewpoints less than 52°F (11.1°C). These tolerances ensure that the systematic error in  $Q_{cfv}$  attributable to neglecting humidity during calibration and measurement is no greater than  $\pm 0.25\%$ . Note that this error attributable to neglecting humidity during calibration and measurement may be reduced to a maximum of  $\pm 0.15\%$  if the calibration and measurement dewpoints are both kept below 38°F (3.3°C). Note also that the minimum allowable dilution air temperature is 59°F (15°C), therefore, controlling dilution air dewpoint below 52°F (11.1°C) to avoid incorporating a dewpoint (molecular weight) measurement into the flow calculation may involve not only refrigeration of dilution air, but also reheat of dilution air. CFV flow equations are as follows:

(i) The standard volume flow rate for a CFV is calculated with the following formula:

$$Q_{cfv} = K_v \times P_{abs} / (T_{abs} \times Mw_{mix})^{1/2} \quad \text{scfm (std m}^3/\text{min)}$$

or, only if  $T_{dc} < 52^\circ\text{F (11.1}^\circ\text{C)} \cap T_{dm} < 52^\circ\text{F (11.1}^\circ\text{C)}$ ,

$$Q_{cfv} = K_v \times P_{abs} / (T_{abs})^{1/2} \quad \text{scfm (std m}^3/\text{min)}$$

Where:

(i)  $Q_{cfv}$  = the volumetric flow rate at standard pressure (29.9213 in Hg@32°F, 101.325 kPa) and standard temperature (68°F deg., 20°C, 527.67 R, 293.15 K).

(ii)  $K_v$  = calibration coefficient. Note that this coefficient has different dimensions in the two different formulas for  $Q_{cfv}$ , and thus it will also have very different values. In the formula that includes the " $Mw_{mix}$ " term,  $K_v$  has dimensions of  $\text{length}^2 \times \text{time} \times (\text{temperature} / \text{mass})^{1/2}$ , while in the other formula,  $K_v$  has dimensions of  $\text{length}^2 \times \text{time} \times \text{temperature}^{1/2} \times \text{mass}^{-1}$

- (iii)  $P_{abs}$  = absolute, static pressure at the inlet to the CFV, e.g. in. Hg@32°F (e.g. kPa)
- (iv)  $T_{abs}$  = absolute temperature at the inlet to the CFV, R (K).
- (v)  $Mw_{mix}$  = molecular weight of the gas mixture, lbm/mol (kg/kmol)
- (vi)  $T_{dc}$  = dewpoint of air used during CFV calibration, °F (°C)
- (vii)  $T_{dm}$  = dewpoint of dilution air during a test, °F (°C).

The calibration procedure described in paragraph (d)(3) of this section establishes the value of the calibration coefficient,  $K_{vs}$ , at values of pressure,  $P_{abs}$ , temperature  $T_{abs}$ , calibration venturi air flow,  $Q_s$ , and dewpoint,  $T_{dc}$ .

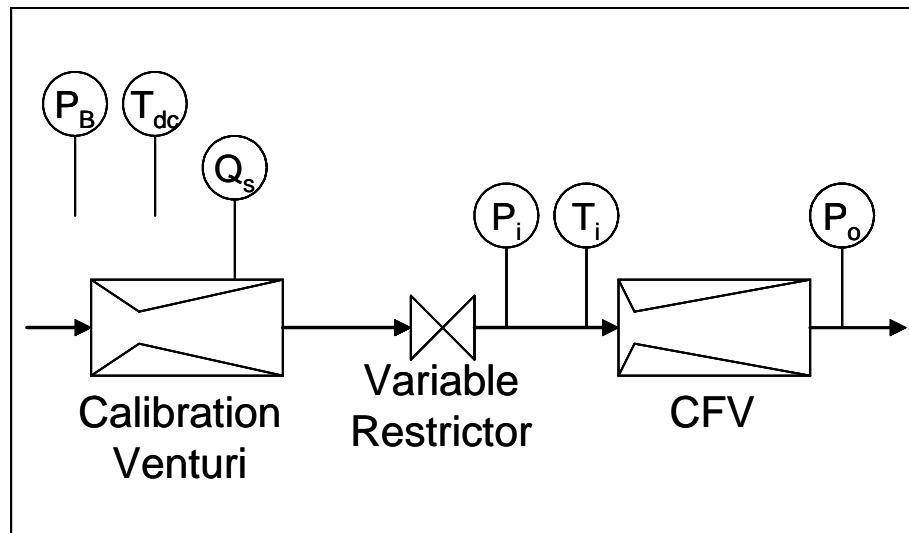
(2) The manufacturer's recommended procedure shall be followed for calibrating electronic portions of the CFV.

(3) Measurements necessary for flow calibration are as follows:

#### CFV Calibration Data Measurements and Tolerances

Parameter	Symbol	Units	Tolerance
Wet barometric absolute pressure	$P_B$	in Hg@32°F (kPa)	$\pm 0.01$ in Hg@32°F ( $\pm 0.034$ kPa)
Dewpoint or frostpoint of the inlet air at the same location as $P_B$	$T_{dc}$ or $T_{fc}$	°F (°C)	$\pm 2.0$ °F (1.1 °C)
Air temperature at the inlet to the calibration venturi	=	°F (°C)	$\pm 2.0$ °F (1.1 °C)
Static pressure drop between inlet to and throat of the calibration venturi	=	in Hg@32°F (kPa)	$\pm 1\%$ of minimum reading
Static gage pressure at the inlet to the CFV, a negative value	$P_i$	in Hg@32°F (kPa)	$\pm 0.05$ in Hg@32°F ( $\pm 0.17$ kPa)
Temperature at CFV inlet	$T_i$	°F (°C)	$\pm 4.0$ °F ( $\pm 2.2$ °C)
Static gage pressure at the outlet of the CFV, a negative value	$P_o$	in Hg@32°F (kPa)	$\pm 0.05$ in Hg@32°F ( $\pm 0.17$ kPa)

(4) Set up equipment as shown in Figure N1319-2 and eliminate leaks. Leaks between the flow measuring devices and the critical flow venturi will seriously affect the accuracy of the calibration.



**Figure 1319-2**

(5) Set the variable flow restrictor to the open position, start the blower, and allow the system to stabilize. Record data from all instruments.

(6) Adjust the variable restrictor and make at least eight readings across the critical flow range of the venturi.

(7) Data analysis. The data recorded during the calibration are to be used in the following calculations:

(i) The air flow rate,  $Q_s$ , at each test point is calculated in standard cubic feet per minute, scfm (std m<sup>3</sup>/min) from the calibration venturi data using the manufacturer's prescribed method.

(ii) Calculate values of the calibration coefficient,  $K_v$ , for each test point:

$$K_v = Q_s \times (T_{abs} \times Mw_{mix})^{1/2} / P_{abs} \quad \text{scfm (std m}^3\text{/min)}$$

or, only if  $T_{dc} \leq 52^\circ\text{F}$  ( $11.1^\circ\text{C}$ )  $\cap$   $T_{dm} \leq 52^\circ\text{F}$  ( $11.1^\circ\text{C}$ ),

$$K_v = Q_s \times (T_{abs})^{1/2} / P_{abs} \quad \text{scfm (std m}^3\text{/min)}$$

Where:

(A)  $Q_s$  = Calibration venturi flow rate in standard cubic feet per minute, at standard pressure (29.9213 in Hg@32°F, 101.325 kPa) and standard temperature (68°F deg., 20° C, 527.67 R, 293.15 K).

(B)  $T_{abs}$  = Absolute temperature at CFV inlet, R (K):  
=  $T_i + 459.67$ ; ( $T_i + 273.15$ )

(C)  $Mw_{mix}$  = molecular weight of the gas mixture, lbm/mol (kg/kmol)

$$Mw_{mix} = \frac{Mw_{air}(P_B - P_{vp}) + Mw_{H_2O}P_{vp}}{P_B} \quad Mw_{mix} = \frac{Mw_{air}(P_B - P_{vp}) + Mw_{H_2O}P_{vp}}{P_B}$$

Where:

$Mw_{air}$  = molecular weight of dry air  
= 28.9644 lbm/lb-mole (kg/kg-mole)

$Mw_{H_2O}$  = molecular weight of water  
= 18.0153 lbm/lb-mole (kg/kg-mole)

$P_{vp}$  = partial pressure of water (vapor pressure) in the inlet air to the calibration venturi, in same units as  $P_B$ .

If dewpoint temperature is measured in or converted to degrees Celsius ( $^\circ\text{C}$ ), the Magnus formula may be used to calculate  $P_{vp}$ :

$$P_{vp} = 0.6113 \times 10^{(7.5 \times T_{dc}) / (237.3 + T_{dc})} \quad \text{kPa}$$

Where:

$T_{dc}$  = dewpoint temperature of the inlet air to the calibration venturi at the same location as  $P_B$ . Note  $T_{dc}$  must be in degrees Celsius ( $^\circ\text{C}$ ) and  $P_{vp}$  will be in kPa.

If frostpoint temperature is measured in or converted to degrees Celsius ( $^\circ\text{C}$ ),

$$P_{vp} = 0.6113 \times 10^{(7.5 \times T_{fc}) / (265.5 + T_{fc})} \quad \text{kPa}$$

Where:

$T_{fc}$  = frostpoint temperature of the inlet air to the calibration venturi at the same location as  $P_B$ . Note  $T_{fc}$  must be in degrees Celsius ( $^\circ\text{C}$ ) and  $P_{vp}$  will be in kPa.

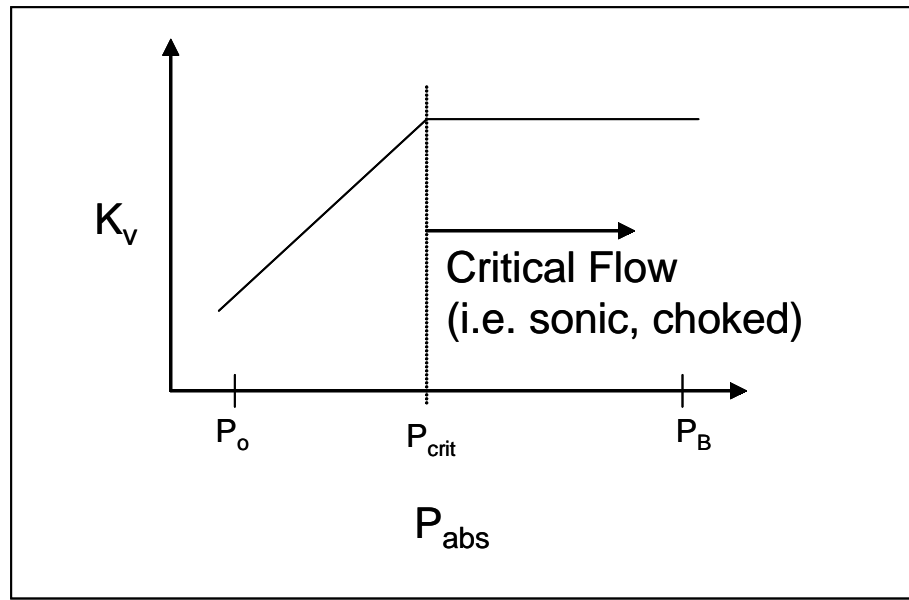
$P_B$  = wet barometric absolute pressure of the inlet air to the calibration venturi at the same location as  $T_{dc}$  in same units as  $P_{vp}$

(D)  $P_{abs} = \text{Absolute pressure at CFV inlet, in. Hg. @32°F (kPa)}$   
 $= P_B + P_i$

Where:

(E)  $P_i = \text{Static gage pressure at the inlet to the CFV, a negative value, in}$   
 $\text{Hg. @32°F (kPa)}$

(iii) Plot  $K_v$  versus  $P_{abs}$ . For choked flow,  $K_v$  will have a relatively constant value. As  $P_{abs}$  decreases at the CFV inlet, the venturi becomes unchoked and  $K_v$  decreases. See Figure 1319-3.



**Figure 1319-3**

(iv) For a minimum of 8 points in the critical flow region calculate an average  $K_v$  and the n-1 standard deviation.

(v) If the standard deviation exceeds 0.3% of the average  $K_v$ , troubleshoot any hardware and software used to perform the experiment, determine any statistical outliers or any data points that may not lie in the critical flow region and take corrective action using sound engineering judgment. Repeat the calibration as necessary to achieve a standard deviation that does not exceed 0.3% of the average  $K_v$ .

(8) Calculate a parameter for monitoring sonic flow in the CFV during exhaust emissions tests:

(i) Option 1. (A) CFV pressure ratio. Based upon the calibration data selected to meet the criteria for paragraphs (d)(7)(iv) and (v) of this section, select the data values associated with the calibration point with the lowest  $P_{abs}$ . With this set of calibration data, calculate the following CFV pressure ratio limit,  $P_{crit}$ :

$$P_{crit} = (P_0 + P_B) / P_{abs}$$

(B) The venturi pressure ratio,  $P_r$ , during all emissions tests must be less than, or equal to  $P_{crit}$  derived from the CFV calibration data, such that:

$$P_r = (P_0 + P_B) / P_{abs} \leq P_{crit}$$

Where  $P_0$ ,  $P_B$ , and  $P_{abs}$  are the real-time values measured during an emissions test.

(ii) Option 2. Other methods: With approval under 86.1306-07, any other method may be used. (9) Use the following procedure for real time calculation of  $Q_{cfv}$  during exhaust emissions tests.

(i) Use the formulas in paragraph (d)(1).

(ii) All inputs to the calculations use the most recent real time values.  
 (iii) If the form of the formulas that includes  $Mw_{mix}$  is required, calculate  $Mw_{mix}$  using the formula in paragraph (d)(2)(C) based on the vapor pressure (i.e. dewpoint or frostpoint) of the dilution air instead of the inlet air to the calibration venturi.

(e) Subsonic Venturi (SSV) calibration.

(1) The calibration of a subsonic venturi (SSV) is based on the flow equation for a subsonic venturi. The gas flow is a function of inlet pressure, inlet temperature, pressure drop between the SSV inlet and throat, and the molecular weight of the gas, which may be determined from a gas flow dewpoint measurement. The working formulas in this section are based on ASME Fluid Meters, Their Theory and Applications, 6<sup>th</sup> ed., 1971. A detailed derivation is expected to be available in a future SAE paper.

(i) The standard volume flow rate for an SSV is calculated with the following formula:

$$Q_s = A_0 d^2 C_d P_{abs} \left[ \frac{1}{Mw_{mix} T_{abs}} (r^{1.4286} - r^{1.7143}) \left( \frac{1}{1 - \beta^4 r^{1.4286}} \right) \right]^{\frac{1}{2}} \text{scfm (std m}^3\text{/min)}$$

where :

$Q_s$  = the volumetric flow rate at standard pressure (1 atm, 29.9213 in Hg@32°F, 101.325 kPa) and temperature (68 °F, 20 °C, 527.67 R, 293.15 K)

$A_0$  = collection of constants and units conversions

$$= 3404.7 \text{ in English units of } \left( \frac{\text{ft}^3}{\text{min}} \right) \left( \frac{^\circ\text{R}}{\text{lb}_m - \text{mole}} \right)^{\frac{1}{2}} \left( \frac{1}{\text{in Hg @ 32}^\circ\text{F}} \right) \left( \frac{1}{\text{in}^2} \right)$$

$$= 0.032891 \text{ in SI units of } \left( \frac{\text{m}^3}{\text{min}} \right) \left( \frac{\text{K}}{\text{kg} - \text{mole}} \right)^{\frac{1}{2}} \left( \frac{1}{\text{kPa}} \right) \left( \frac{1}{\text{mm}^2} \right)$$

$d$  = diameter of the SSV throat, inch (mm)

$C_d$  = discharge coefficient of the SSV = actual flow / theoretical flow

$P_{abs}$  = absolute, static pressure at the inlet to the SSV, in Hg@32°F (kPa)

=  $P_B - P_i$

$Mw_{mix}$  = molecular weight of the gas mixture, lb<sub>m</sub>/lb-mole (kg/kg-mole)

$T_{abs}$  = absolute temperature at the inlet to the SSV, °R (K)

=  $T_i + 459.67$  English units ( $T_i + 273.15$  SI Units)

$r$  = ratio of the SSV throat to inlet absolute, static pressures

=  $1 - \Delta P / P_{abs}$

$\beta$  = ratio of the SSV throat diameter,  $d$ , to the inlet (approach) pipe inner diameter,

$\frac{D}{d}$   
 =  $d/D$

where:

$P_B$  = absolute atmospheric pressure (local, wet barometer), in Hg@32°F (kPa)

$T_i$  = temperature at the inlet to the SSV, °F (°C)

$P_i$  = gage pressure at the inlet to the SSV, in Hg@32°F (kPa)

$\Delta P$  = static pressure drop between inlet to and throat of the SSV, in Hg@32°F (kPa).

$D$  = inside diameter of the approach pipe (tunnel), inches (mm)

(ii) The molecular weight of the gas mixture, is calculated with the following formula:

$$Mw_{mix} = \frac{Mw_{air} (P_B - P_{vp}) + Mw_{H_2O} P_{vp}}{P_B}$$

where:

$Mw_{air}$  = molecular weight of dry air

= 28.9644 lbm/lb-mole (kg/kg-mole)  
Mw<sub>H<sub>2</sub>O</sub> = molecular weight of water  
                     = 18.0153 lbm/lb-mole (kg/kg-mole)  
P<sub>vp</sub> = partial pressure of water (vapor pressure) in the inlet air to the calibration venturi, in same units as P

If dewpoint temperature is measured in or converted to degrees Celsius (°C), the Magnus formula may be used to calculate P<sub>vp</sub>:

$$\underline{P_{vp}} = 0.6113 \times 10^{(7.5 \times T_{dc}) / (237.3 + T_{dc})} \quad \text{kPa}$$

Where:  
T<sub>dc</sub> = dewpoint temperature of the inlet air to the calibration venturi at the same location as P<sub>B</sub>. Note T<sub>dc</sub> must be in degrees Celsius (°C) and P<sub>vp</sub> will be in kPa.

If frostpoint temperature is measured in or converted to degrees Celsius (°C),

$$\underline{P_{vp}} = 0.6113 \times 10^{(7.5 \times T_{fc}) / (265.5 + T_{fc})} \quad \text{kPa}$$

Where:  
T<sub>fc</sub> = frostpoint temperature of the inlet air to the calibration venturi at the same location as P<sub>B</sub>. Note T<sub>fc</sub> must be in degrees Celsius (°C) and P<sub>vp</sub> will be in kPa.

P<sub>B</sub> = wet barometric absolute pressure of the inlet air to the calibration venturi at the same location as T<sub>dc</sub>, in same units as P<sub>vp</sub>

(iii) The C<sub>d</sub> of the SSV is determined by a calibration curve fit equation that is a function of Reynolds number, Re, at the SSV throat. The Re at the SSV throat is calculated with the following formula:

$$\text{Re} = A_1 \frac{Q_s \text{Mw}_{\text{mix}}}{d\mu}$$

where:

A<sub>1</sub> = a collection of constants and units conversions (m<sup>4</sup>/kmol, ft<sup>4</sup>/lb-mol) = 6.6086x10<sup>-4</sup> English units (0.88217 SI units)

μ = the absolute or dynamic viscosity of the gas and is calculated with the following formula:

$$\mu = \frac{bT_{\text{abs}}^{3/2}}{S + T_{\text{abs}}} = \frac{bT_{\text{abs}}^{1/2}}{1 + \frac{S}{T_{\text{abs}}}} \quad \text{lb}_m/\text{ft-s (kg/m-s)}$$

where:

b = empirical constant based on the US standard atmosphere  
 = 7.302 x 10<sup>-7</sup> lb<sub>m</sub>/ft-s-°R<sup>1/2</sup> (1.458 x 10<sup>-6</sup> kg/m-s-K<sup>1/2</sup>)  
S = empirical constant based on the US standard atmosphere  
 = 198.72 °R (110.4 K)

(2) Analog computing devices on the SSV are not allowed. All calculations must be executed on digital computers.

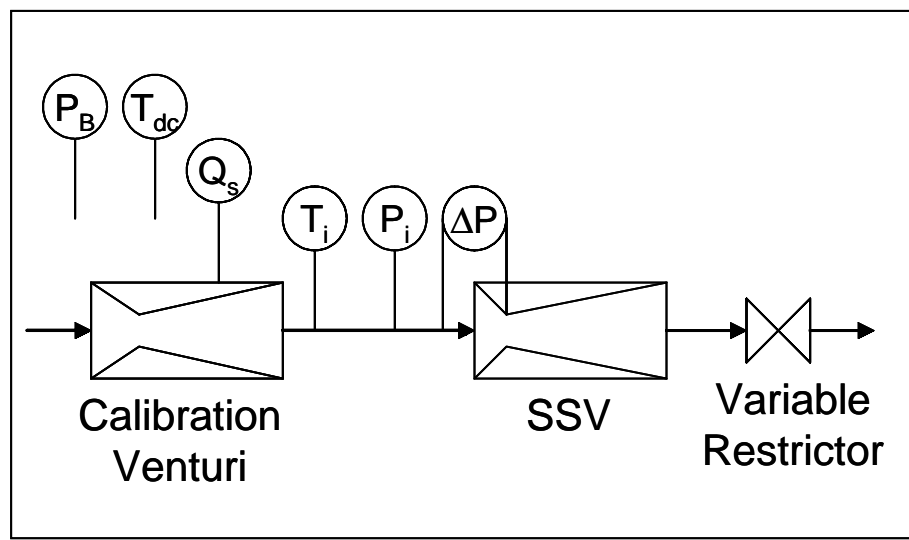
(3) Measurements necessary for flow calibration of the SSV are as follows:

SSV Calibration Data Measurements and Tolerances

<b>Parameter</b>	<b>Symbol</b>	<b>Units</b>	<b>Tolerance</b>
<u>Wet barometric absolute pressure</u>	$P_B$	<u>in Hg@32°F (kPa)</u>	<u>± 0.01 in Hg@32°F (± 0.034 kPa)</u>
<u>Dewpoint or frostpoint of the inlet air at the same location as <math>P_B</math></u>	$T_d$ or $T_f$	<u>°F (°C)</u>	<u>± 2.0 °F (1.1 °C)</u>
<u>Air temperature at the inlet to the calibration venturi</u>	$T_i$	<u>°F (°C)</u>	<u>± 2.0 °F (1.1 °C)</u>
<u>Static pressure drop between inlet to and throat of the calibration venturi</u>	$\Delta P$	<u>in Hg@32°F (kPa)</u>	<u>± 1% of minimum reading</u>
<u>Temperature at SSV inlet</u>	$T_i$	<u>°F (°C)</u>	<u>± 4.0 °F (± 2.2 °C)</u>
<u>Static depression (vacuum) at the inlet to the SSV</u>	$P_i$	<u>in Hg@32°F (kPa)</u>	<u>± 0.017 in Hg@32°F (± 0.057 kPa)</u>
<u>Static pressure drop between inlet to and throat of the SSV</u>	$\Delta P$	<u>in Hg@32°F (kPa)</u>	<u>± 1% of minimum reading</u>

(4) Set up equipment as shown in Figure 1319-4 and eliminate leaks. Leaks between the flow measuring devices and the critical flow venturi will seriously affect the accuracy of the calibration.

**Figure 1319-4**



The calibration must be conducted with the SSV installed in its permanent position. Subsequent changes in upstream or downstream configuration could cause a shift in calibration.

(5) Adjust the flow, using a variable speed blower or valve downstream of the SSV, to a value above the maximum in-use Reynolds number at the SSV throat. Allow the system to stabilize and record data from all instruments. Be sure to avoid choked (sonic or critical) flow.

(6) Vary the flow through a minimum of 16 steps covering the intended in-use operating range of the SSV. Use good engineering judgment to select the points. Allow the system to stabilize and record data from all instruments at each flow point.

(7) Calibration Data analysis:

(i) Calculate  $Q_s$  from the calibration venturi data at each calibration point. Use the method prescribed by the NIST traceable calibration, which should follow very similar flow equations to the SSV. For a free standing calibration venturi its  $\beta = 0$  and  $P_{abs} = P_B$ . The formula in paragraph (e)(1)(iii) may be used to calculate the  $Re$  of the calibration venturi throat by substituting the throat diameter of the calibration venturi used by the NIST traceable calibration. Because  $Q_s$  is an input to the  $Re$  formula, the calculations must be started with an initial guess for  $Q_s$  or  $C_d$  of the calibration venturi, and repeated until  $Q_s$  converges. The convergence method must be accurate to 0.1% of point or better.

(ii) Calculate the SSV  $C_d$  and  $Re$  at each calibration point.  $C_d$  is calculated by solving the formula in paragraph (e)(1)(i) for  $C_d$ . Establish an equation of  $C_d$  as a function of  $Re$  using good engineering practice. Many factors affect the functional relationship of the  $C_d$  with  $Re$  including geometry and installation of the SSV and  $Re$  range. Various functional forms may be used and different forms may be used over different  $Re$  ranges. At lower  $Re$ , a common functional form is  $C_d = a_0 - a_1 Re^{-1/2}$ , where  $a_0$  and  $a_1$  are coefficients calculated from a least squares regression of the calibration data. Polynomials are another, more general, functional form. The calculated values of  $C_d$  from the resulting calibration curve fit equation must be within  $\pm 0.5\%$  of the measured  $C_d$  for each calibration point.

(8) Use the following procedure for real time calculation of  $Q_s$  during exhaust emissions tests.

(i) Use the formulas in paragraph (e)(1).

(ii) Initialize the real time calculation with either a reasonable value for  $C_d$ , such as 0.98, or a reasonable value of  $Q_s$ . If the calculation is initialized with  $Q_s$ , use the initial value of  $Q_s$  to evaluate  $Re$ , which is then input to the calibration curve developed in paragraph (e)(7)(ii) to calculate the initial value of  $C_d$ .

(iii) On subsequent iterations, use the previously calculated value of  $Q_s$  to evaluate  $Re$ , which is then input to the calibration curve developed in paragraph (e)(7)(ii) to calculate  $C_d$ . No iteration is required since  $Q_s$  changes little between calculations.

(iv) All other inputs to the calculations use the most recent real time values.

(v)  $Mw_{mix}$  is calculated using the formula in paragraph (e)(1)(ii) based on the vapor pressure (i.e. dewpoint or frostpoint) of the dilution air instead of the inlet air to the calibration venturi. If dilution air is controlled during exhaust emissions tests so that its  $Mw_{mix}$  is maintained within  $\pm 0.3\%$  of a nominal value, then the  $Mw_{mix}$  of the dilution air may optionally be treated as a constant in the real time calculation of  $Q_s$  during exhaust emissions tests. For this option, the constant used for the dilution air  $Mw_{mix}$  in the real time calculation of  $Q_s$  during exhaust emissions tests must be the nominal  $Mw_{mix}$  value based on either the dilution air humidity set point and a typical barometer or the average value observed in operation.

(vi) During all emissions tests, the Reynolds number at the SSV throat must be in the range of Reynolds numbers used to derive the calibration curve developed in paragraph (e)(7)(ii).

(f) CVS system verification.

The following "gravimetric" technique can be used to verify that the CVS and analytical instruments can accurately measure a mass of gas that has been injected into the system. (Verification can also be accomplished by constant flow metering using critical flow orifice devices.)

(1) Obtain a small cylinder that has been charged with pure propane or carbon monoxide gas (CAUTION—carbon monoxide is poisonous).

(2) Determine a reference cylinder weight to the nearest 0.01 grams. (3) Operate the CVS in the normal manner and release a quantity of pure propane into the system during the sampling period (approximately 5 minutes).

(5) The emissions calculations are performed in the normal way except in the case of propane. The density of propane (17.30 g/ft<sup>3</sup>/carbon atom (0.6109 kg/m<sup>3</sup>/carbon atom)) is used in place of the density of exhaust hydrocarbons.

(6) The gravimetric mass is subtracted from the CVS measured mass and then divided by the gravimetric mass to determine the percent accuracy of the system.

(7) The cause for any discrepancy greater than  $\pm 2$  percent must be found and corrected.

~~{Reserved}~~

#### **§ 1065.315 Torque calibration.**

You must use one of two techniques to calibrate torque: the lever-arm deadweight or the transfer technique. You may use other techniques if you show they are equally accurate. The NIST “true value” torque is defined as the torque calculated by taking the product of an NIST traceable weight or force and a sufficiently accurate horizontal distance along a lever arm, corrected for the lever arm’s hanging torque.

(a) The lever-arm dead-weight technique involves placing known weights at a known horizontal distance from the torque-measuring device’s center of rotation. You need two types of equipment:

(1) *Calibration weights.* This technique requires at least six calibration weights for each range of torque-measuring device used. Equally space the weights and make sure each one is traceable to NIST weights.

You also may use weights certified by a U.S. state government’s bureau of weights and measures. If your laboratory is outside the U.S., see § 1065.305 for information about using non-NIST standards. You may account for effects of changes in gravitational constant at the test site.

(2) *Lever arm.* This technique also requires a lever arm at least 20 inches long. Make sure the horizontal distance from the torque-measurement device’s centerline to the point where you apply the weight is accurate to within  $\pm 0.10$  inches. You must balance the arm or know its hanging torque to within  $\pm 0.1$  ft-lbs.

(b) The transfer technique involves calibrating a master load cell (dynamometer case load cell). You may calibrate the master load cell with known calibration weights at known horizontal distances. Or you may use a hydraulically actuated, precalibrated, master load cell and then transfer this calibration to the device that measures the flywheel torque. The transfer technique involves three main steps:

(1) Precalibrate a master load cell or calibrate it following paragraph (a)(1) of this section. Use known weights traceable to NIST with the lever arms specified in paragraph (b)(2) of this section. Run or vibrate the dynamometer during this calibration to reduce static hysteresis.

(2) Use lever arms at least 20 inches long. The horizontal distances from the master load cell’s centerline to the dynamometer’s centerline and to the point where you apply weight or force must be accurate to within  $\pm 0.10$  inches.

Balance the arms or know their net hanging torque to within  $\pm 0.1$  ft-lbs.

(3) Transfer calibration from the case or master load cell to the torque measuring device with the dynamometer operating at a constant speed. Calibrate the torque measurement device’s readout to the master load cell’s torque readout at a minimum of six loads spaced about equally across the full useful ranges of both measurement devices. (Good engineering practice requires that both devices have about the same useful ranges of torque measurement.) Transfer the calibration so it meets the accuracy requirements in § 1065.105(a)(2) for readouts from the torque-measurement device.

#### **§ 1065.320 Flow measurement instrument calibration.**

The flow measurement instrumentation shall be calibrated at least once per year or whenever a system repair or change is made that could influence calibration.

### **Subpart E—Engine Selection, Preparation, and Service Accumulation**

#### **§ 1065.401 Selecting a test engine.**

While all engine configurations within a certified engine family must comply with the applicable standards in the standard-setting part, you are not required to test each configuration for certification.

(a) Select for testing according to the following guidance the engine configuration within the engine family that is most likely to exceed an emission standard:

(1) Test the engine that we specify, whether we do this through general guidance or give you specific instructions.

(2) If we do not tell you which engine to test, follow any instructions in the standard-setting part.

(3) If we do not tell you which engine to test and the standard-setting part does not include specifications for selecting test engines, use good engineering judgment to select the engine configuration within the engine family that is most likely to exceed an emission standard.

(b) In the absence of other information, the following characteristics are appropriate to consider when selecting the engine to test:

- (1) Maximum fueling rates.
- (2) Maximum in-use engine speed (governed or ungoverned, as applicable).
- (3) Highest sales volume.
- (c) We may select any engine configuration within the engine family for our testing.

**§ 1065.405 Preparing and servicing a test engine.**

- (a) If you are testing an emission-data engine for certification, make sure you have built it to represent production engines.
- (b) Run the test engine, with all emission-control systems operating, long enough to stabilize emission levels. If you accumulate 50 hours of operation, you may consider emission levels stable without measurement.
- (c) Do not service the test engine before you stabilize emission levels, unless we approve other maintenance in advance. This prohibition does not apply to your recommended oil and filter changes for newly produced engines, or to idle-speed adjustments.
- (d) Select engine operation for accumulating operating hours on your test engines to represent normal in-use operation for the engine family.
- (e) If you need more than 50 hours to stabilize emission levels, record your reasons and the method you use to do this. Give us these records if we ask for them.

**§ 1065.410 Service limits for stabilized test engines.**

- (a) After you stabilize the test engine's emission levels, you may do scheduled maintenance, other than during emission testing, as the standard-setting part specifies.
- (b) You may not do any unscheduled maintenance to the test engine or its emission-control system or fuel system without our advance approval. Unscheduled maintenance includes adjusting, repairing, removing, disassembling, cleaning, or replacing the test engine. We may approve routine maintenance that is not scheduled such as maintaining the proper oil level.
  - (1) We may approve other unscheduled maintenance if all of the following occur:
    - (i) You determine that a part failure or system malfunction (or the associated repair) does not make the engine unrepresentative of production engines in the field and does not require anyone to access the combustion chamber.
    - (ii) Something clearly malfunctions (such as persistent misfire, engine stall, overheating, fluid leakage, or loss of oil pressure) and needs maintenance or repair.
    - (iii) You give us a chance to verify the extent of the malfunction before you do the maintenance.
  - (2) If we determine that a part's failure or a system's malfunction (or the associated repair) has made the engine unrepresentative of production engines, you may no longer use it as a test engine.
  - (3) You may not do unscheduled maintenance based on emission measurements from the test engine.
  - (4) Unless we approve otherwise in advance, you may not use equipment, instruments, or tools to identify bad engine components unless you specify they should be used for scheduled maintenance on production engines. In this case, if they are not generally available, you must also make them available at dealerships and other service outlets.
- (c) If you do maintenance that might affect emissions, you must completely test the engine for emissions before and after the maintenance, unless we waive this requirement.
- (d) If your test engine has a major mechanical failure that requires you to take it apart, you may no longer use it as a test engine.

**§ 1065.415 Durability demonstration.**

If the standard-setting part requires durability testing, you must accumulate service in a way that represents how you expect the engine to operate in use. You may accumulate service hours using an accelerated schedule, such as through continuous operation.

- (a) *Maintenance.* The following limits apply to the maintenance that we allow you to do on test engine:
  - (1) You may perform scheduled maintenance that you recommend to operators, but only if it is consistent with the standard-setting part's restrictions.
  - (2) You may perform additional maintenance only if we approve it in advance, as specified in § 1065.410(b).
  - (3) If your test engine has a major mechanical failure that requires you to take it apart, you may no longer use it as a test engine.

- (b) *Emission measurements.* You must measure emissions following two main requirements: (1) Perform emission tests to determine deterioration factors consistent with good engineering judgment. Evenly space any tests between the first and last test points throughout the durability period.
- (2) Perform emission tests following the provisions of this part and the standard-setting part.

## **Subpart F—Running an Emission Test**

### **§ 1065.501 Overview of the engine dynamometer test procedures.**

#### Engine dynamometer test procedures; overview.

(a) The engine dynamometer test procedure is designed to determine the brake specific emissions of hydrocarbons, nonmethane hydrocarbons, carbon monoxide, oxides of nitrogen, particulate.

(b) Engine torque and rpm command set points shall be issued at 5 (10 Hz recommended) Hz or greater during both the cold and hot start tests. Feedback engine torque and rpm shall be recorded at least once every second during the test.

(c) Using the torque and rpm feedback signals, integrate the brake horsepower with respect to time. This produces a brake horsepower-hour value that enables the brake-specific emissions to be determined.

(3) On air-cooled engines, the fan shall be installed.

(4) Additional accessories (e.g., oil cooler, alternators, air compressors, etc.) may be installed or their loading simulated if typical of the in-use application.

This loading shall be parasitic in nature and, if used, shall be applied during all engine testing operations, including mapping. The accessory work performed shall not be included in the integrated work used in emissions calculations.

(5) The engine may be equipped with a production-type starter.

(e) Means of engine cooling that will maintain the engine operating temperatures

(e.g., temperatures of intake air, oil, water, etc.) at approximately the same temperature as specified by the manufacturer shall be used. An auxiliary fan(s) may be used to maintain engine cooling during operation on the dynamometer. Rust inhibitors and lubrication additives may be used, up to the levels recommended by the additive manufacturer. Antifreeze mixtures and other coolants typical of those approved for use by the manufacturer may be used.

(f) Exhaust system. The exhaust system term shall meet the following requirements:

(2) Petroleum-fueled diesel engines. Either a chassis type or a facility-type exhaust system or both systems simultaneously may be used. If the engine is equipped with an exhaust aftertreatment device, the exhaust pipe must be the same diameter as found in-use for at least 4 pipe diameters upstream to the inlet of the beginning of the expansion section containing the aftertreatment device. The catalyst container may be removed during all test sequences prior to the practice cycle, and replaced with an equivalent container having an inactive catalyst support.

(i) The engine exhaust systems shall meet the following requirements:

(A) The total length of the tubing from the exit of the engine exhaust manifold, turbocharger outlet or aftertreatment device to the primary dilution tunnel shall not exceed 32 feet (9.8 m).

(B) The initial portion of the exhaust system may consist of a typical in-use (i.e., length, diameter, material, etc.) chassis-type exhaust system.

(C) The distance from the exhaust manifold flange(s) or turbocharger outlet to any exhaust aftertreatment device shall be the same as in the vehicle configuration or within the distance specifications provided by the manufacturer.

(D) For engines which are not equipped with exhaust aftertreatment devices, all tubing in excess of 12 feet (3.7 m) from the exit of the turbocharger or exhaust manifold shall be insulated. For engines equipped with exhaust aftertreatment devices, all tubing after the aftertreatment device which is in excess of 12 feet (3.7 m) shall be insulated.

(E) The thermal conductivity of the insulating material must have a value no greater than 0.75 BTU-in/hr/ft<sup>2</sup>/°F (0.065 W/m-K) measured at 700 °F (371 °C).

(F) A smoke meter or other instrumentation may be inserted into the exhaust system tubing. If this option is exercised in the insulated portion of the tubing, then a minimal amount of tubing not to exceed 18 inches may be left uninsulated. However, no more than 12 feet (3.66 m) of tubing can be left uninsulated in total, including the length at the smoke meter.

(ii) The facility-type exhaust system shall meet the following requirements:

(A) It must be composed of smooth tubing made of typical in-use steel or stainless steel.  
(B) Short sections (altogether not to exceed 20 percent of the entire tube length) of flexible tubing at connection points are allowed.

Test sequence; general requirements.

(a) The test sequence shown shows the major steps of the test procedure.

(b) Control of Air Temperature. (1) The temperature of the CVS dilution air shall be maintained above 68 °F (20 °C) for Otto cycle engines and between 68 °F and 86 °F (20 °C and 30 °C) for diesel cycle engines throughout the test sequence.

(2) For engines with auxiliary emission control devices which sense or detect ambient air temperature and operate at 68 °F or higher, the test cell ambient air temperature and the temperature of the engine intake air shall be maintained at 77 °F ±9 °F (25 °C ±5 °C) throughout the test sequence. For engines with auxiliary emission control devices which are temperature dependent and operate at 68 °F or higher, the temperature of the engine intake air shall be maintained at 77 °F ±9 °F (25 °C ±5 °C) throughout the test sequence.

(3) For engines which are not equipped with temperature dependent auxiliary emission control devices, the test cell ambient air temperature and the temperature of the engine intake air shall be greater than 20° C (68° F). No corrections will be made in test results or measured engine power if 30° C (86° F) is exceeded.

(5) For engines equipped with an air to- air intercooler (or any other low temperature charge air cooling device) between the turbocharger compressor and the intake manifold, the procedure for simulating the device in the transient dynamometer test facilities shall follow the SAE Recommended Practice J1937, "Engine Testing with Low Temperature Charge Air Cooling System in a Dynamometer Test Cell" or equivalent practice.

(c) No control of ambient air, engine intake air or CVS dilution air humidity is required.

(d) The idle test of subpart P may be run after completion of the hot start exhaust emission test, if applicable.

(f) Diesel-Fueled Engines only.

(1)(i) Air inlet restriction shall be set to a value midway between a clean filter and the maximum restriction specified by the manufacturer. The exhaust restriction normally shall be set at 80 percent of the manufacturer's recommended maximum specified exhaust restriction. The manufacturer shall be liable for emission compliance from the minimum in-use restrictions to the maximum restrictions specified by the manufacturer for that particular engine.

(ii) Inlet depression and exhaust backpressure shall be set with the engine operating at rated speed and wide open throttle, except for the case of inlet depression for naturally aspirated engines, which shall be set at maximum engine speed and nominal zero load (high idle).

(iii) The location at which the inlet depression and exhaust backpressure is measured shall be specified by the manufacturer.

(a) The manufacturer is liable for emission compliance over the full range of restrictions that are specified by the manufacturer for that particular engine.

(b) Perform testing at the following inlet and exhaust restriction settings.

(1) Equip the test engine with an air inlet system presenting an air inlet restriction within 5 percent of the upper limit at maximum air flow, as specified by the engine manufacturer for a clean air cleaner. A system representative of the installed engine may be used. In other cases a test shop system may be used.

(2) The exhaust backpressure must be within 5 percent of the upper limit at maximum declared power, as specified by the engine manufacturer.

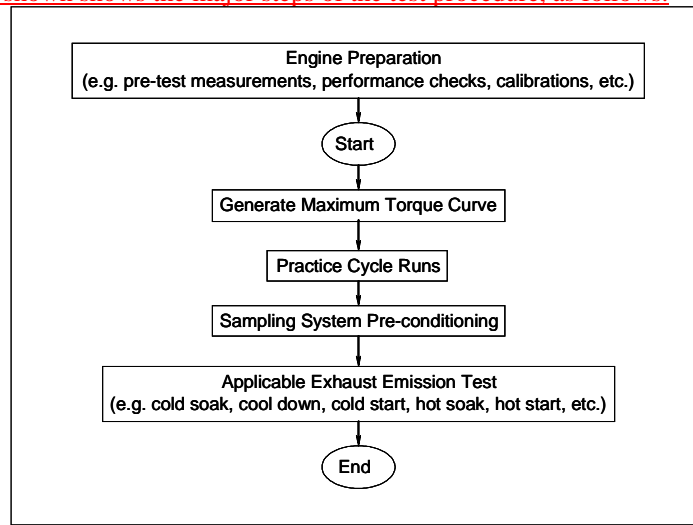
(iv) The settings shall take place during the final mode of the preconditioning prior to determining the maximum torque curve.

(2)(i) The temperature of the inlet fuel to the engine shall not exceed manufacturer requirements.

(ii) The pressure of the inlet fuel and the point at which it is measured shall be specified by the manufacturer.

(g) Pre-test engine measurements (e.g., governed diesel-fueled engine high idle speed, diesel-fueled engine fuel flows, etc.), pre-test engine performance checks (e.g., verification of actual rated rpm, etc.) and pre-test system calibrations (e.g., inlet and exhaust restrictions, etc.) shall be made prior to generation of the maximum torque curve. This can be done during engine preconditioning, or at the manufacturer's convenience subject to the requirements of good engineering practice.

(a) The test sequence shown shows the major steps of the test procedure, as follows:



(a) The engine dynamometer test procedure measures brake-specific emissions of hydrocarbons (total and nonmethane, as applicable), carbon monoxide, and oxides of nitrogen. To perform this test procedure, you first dilute exhaust emissions with ambient air and collect a continuous proportional sample for analysis, then analyze the composite samples (either in bags after the test or continuously during the test). The general test procedure consists of a test cycle made of one or more segments (check the standard-setting part for specific cycles):

(1) Either a cold-start cycle (where you measure emissions) or a warm-up cycle (where you do not measure emissions).

(2) A hot-start transient test (some test cycles may omit engine starting from the “hot-start” cycle).

(3) A steady-state test.

(b) Measure power using the dynamometer’s feedback signals for torque and speed. The power measurement produces a brake kilowatt-hour value that allows you to calculate brake-specific emissions (see Subpart G of this part).

(c) Prepare engines for testing consistent with § 1065.10(c)(1) and according to the following provisions:

(1) When you test an engine or operate it for service accumulation, use the complete engine with all emission control devices installed and functioning.

(2) Install the fan for any air-cooled engine (if applicable).

(3) You may install accessories such as an oil cooler, alternators, and air compressors or simulate their loading if they are typical of in-use operation. Apply this loading during all testing operations, including mapping.

(4) You may install a production-type starter on the engine.

(5) Cool the engine in a way that will maintain its operating temperatures including the intake air, oil, water temperatures about the same as they would be during normal operation. You may use auxiliary fans if necessary. You may use rust inhibitors and lubrication additives, up to the levels that the additive manufacturer recommends. You may also use antifreeze mixtures and other coolants typical of those approved for use by the manufacturer.

(6) Use representative exhaust and air intake systems. Make sure the exhaust restriction is 80 to 100 percent of the recommended maximum specified exhaust restriction and the air inlet restriction is between that of a clean filter and the maximum restriction specification. As the manufacturer, you are liable for emission compliance from the minimum in-use restrictions to the maximum restrictions you specify for that particular engine.

#### **§ 1065.510 Engine mapping procedures.**

(a) *Torque map.* Map your engine’s torque while it is mounted on the dynamometer. Use the torque curve resulting from the mapping to convert the normalized torque values in the engine cycle to actual torque values for the test cycle. Make sure the speed ranges at least from the warm no-load idle speed to 105 percent of the maximum test speed. Because you determine the maximum test speed from the torque map, you may have to perform a preliminary torque map to determine the full mapping range. You may perform this preliminary torque map while the engine warms up. To map the engine, do the following things in sequence:

(1) Warm up the engine so oil and water temperatures (on an absolute scale such as the Kelvin scale) vary by less

than two percent for two minutes; or until the thermostat opens if the engine coolant system includes a thermostat.

(2) Operate the engine at the warm no load idle speed.

(3) Fully open the throttle.

(4) While maintaining wide-open throttle and full-load, keep the engine at minimum speed for at least 15 seconds. Record the average torque during the last 5 seconds.

(5) In increments of  $100 \pm 20$  rpm, determine the maximum torque curve for the full speed range. Hold each test point for 15 seconds and record the average torque over the last 5 seconds. You may use larger increments for engines with maximum test speed over 4000 rpm, as long as you include at least 40 points and space them evenly.

(6) Fit all data points recorded with a cubic spline, Akima, or other technique we approve in advance. The resultant curve must be accurate to within  $\pm 1.0$  ft-lbs. of all recorded engine torques.

(b) *Torque map with continual engine speed sweep.* In place of paragraphs (a)(1) through (a)(4) of this section, you may do a continual sweep of engine speed. While operating at wide-open throttle, increase the engine speed at an average rate of  $8 \pm 1$  rpm/sec over the full speed range. You may use higher sweeping rates for naturally-aspirated engines, in accordance with good engineering judgment. Record speed and torque points at a rate of at least one point per second. Connect all points generated under this approach by linear interpolation.

(c) *Alternate mapping.* You may use other mapping techniques if you believe those in paragraphs (a) and (b) of this section are unsafe or unrepresentative for any engine or engine family. These alternate techniques must satisfy the intent of the specified mapping procedures—to determine the maximum available torque at all engine speeds that occur during the test cycles. Report deviations from this section's mapping techniques for reasons of safety or representativeness. In no case, however, may you use descending continual sweeps of engine speed for governed or turbocharged engines.

(d) *Replicate tests.* You need not map an engine before every test, but you do need to remap the engine in any of the following situations:

(1) Good engineering judgment determines that an unreasonable amount of time has passed since the last map.

(2) The barometric pressure before the test begins has changed more than 25 mm Hg from the average barometric pressure observed during the map.

(3) The engine has undergone physical changes or recalibration that might affect its performance.

(e) *Power map.* Where applicable, generate a power map using the procedures this section specifies for torque maps. You may generate the power map directly or convert the torque map to a power map using engine speeds. The power map is also called a lug curve.

(f) *Cycles based only on torque/power at maximum test speed.* If the applicable test cycle for your engine does not require map information for engine speeds other than the maximum test speed, you may make the following simplifications:

(1) You need not perform the entire torque or power map, as long as you map the engines for speeds between 75 and 105 percent of the maximum test speed.

(2) You need not remap an engine according to paragraph (d) of this section. You need only verify the maximum torque or power at maximum test speed.

#### **§ 1065.512 Diesel engine mapping procedures.**

(a) Mount test engine on the engine dynamometer.

(b) Determine minimum mapping speed. The minimum speed is defined as the warm engine curb idle rpm.

(c) Determine maximum mapping speed per the following methodologies.

(Note paragraph (d)(1) below.)

(1) (i) For ungoverned engines using the transient operating cycle set forth in paragraph (f)(1) of appendix I to this part, the maximum mapping speed shall be no less than that calculated from the following equation:

$$\text{Maximum speed} = \text{curb idle rpm} + \frac{105 (\text{measured rated rpm} - \text{curb idle rpm})}{100}$$

or when a 3.0 percent drop in maximum horsepower occurs, whichever of the two is greater

(ii) For ungoverned engines using the transient operating cycle set forth in paragraph (f)(3) of appendix I to this part, the maximum mapping shall be no less than that calculated from the following equation:

$$\text{Maximum speed} = \text{curb idle rpm} + \frac{115 (\text{measured rated rpm} - \text{curb idle rpm})}{100}$$

or when a 3.0 percent drop in maximum horsepower occurs, whichever of the two is greater.

(iii) For governed engines the maximum mapped speed shall be no less than either that speed at which the wide-open throttle torque drops off to zero, or the maximum speed as calculated for ungoverned engines (paragraph (c)(1)(i) of this section)

(2) Diesel engines. (i) For ungoverned engines, the maximum mapping speed shall be no less than that calculated from the following equation:

$$\text{Maximum speed} = \text{curb idle rpm} + \frac{113 (\text{measured rated rpm} - \text{curb idle rpm})}{100}$$

or when a 3.0 drop in horsepower occurs, whichever of the two is greater

(ii) For governed engines, the maximum mapping speed shall be no less than either that speed at which wide open throttle torque drops off to zero, or the maximum speed as calculated for ungoverned engines (paragraph (c)(2)(i) of this section).

(d) Perform an engine power map.

(1) During engine preparation or warm-up, the engine may be operated such that a preliminary estimate of measured rated rpm can be made.

(2) (i) For a cold engine, start the engine and operate at zero load in accordance with the manufacturer's start-up and warm-up procedures for 1 minute  $\pm$ 30 seconds.

(ii) Operate the engine at a torque equivalent to 10 $\pm$ 3 percent of the most recent determination of maximum torque for 4 minutes  $\pm$ 30 seconds at 2000 rpm.

(iii) Operate the engine at a torque equivalent to 55 $\pm$ 5 percent of the most recent determination of maximum torque for 35 minutes  $\pm$ 1 minute at 2000 rpm.

(iv) Operate the engine at idle (minimum speed).

(v) Open the throttle fully.

(vi) While maintaining wide-open throttle and full-load, maintain minimum engine speed for at least 15 seconds.

Record the average torque during the last 5 seconds.

(vii) In no greater than 100 $\pm$ 20 rpm increments, determine the maximum torque curve from minimum speed to maximum speed. Hold each test point for 15 seconds, and record the average torque over the last 5 seconds.

(viii) Alternate mapping technique. In place of paragraphs (d)(2) (vi) and (vii) of this section, a continual sweep of rpm is allowed. While operating at wide-open throttle, the engine speed is increased at an average rate of 8 rpm/sec ( $\pm$ 1 rpm/sec) from minimum speed to maximum speed. Speed and torque points shall be recorded at a sample rate of at least one point per second.

(ix) Recalculate the maximum speed per paragraph (c)(1) (i) or (ii) of this section using the measured rated speed derived from the new maximum torque curve. If the new maximum speed lies outside the range of speeds encompassed by the actual map, then the map shall be considered void, and another map will need to be run using the newly derived measured rated speed in all calculations.

(x) For warm engines, the entire warm-up procedure specified in paragraphs (d)(2) (i) through (iii) of this section need not be repeated. It is sufficient for an engine already at normal operating temperatures to be operated at the conditions specified in paragraph

(d)(2)(iii) of this section until oil and water temperatures are stabilized, after which the procedures of paragraph (d)(2) (iv) through (vii) of this section may be performed. The oil and water temperatures are defined as stabilized if they are maintained within 2 percent of point for 2 minutes.

(3) Diesel engines. (i) If the engine is cold, start and operate at free idle for 2 to 3 minutes.

(ii) Operate the engine at approximately 50 percent power at the peak torque speed for 5 to 7 minutes.

(iii) Operate the engine at rated speed and wide-open throttle for 25 to 30 minutes.

(iv) Option. The engine may be preconditioned by operating at rated speed and maximum horsepower until the oil and water temperatures are stabilized. The temperatures are defined as stabilized if they are maintained within 2 percent of point for 2 minutes. This optional procedure may be substituted for paragraph (d)(3)(iii) of this section.

(v) Unload the engine and operate at the curb idle speed.

(vi) Operate the engine at wide open throttle and minimum engine speed. Increase the engine speed at an average rate of 8 rpm/sec ( $\pm$ 1 rpm/sec) from minimum to maximum speed. Engine speed and torque points shall be recorded at a sample rate of at least one point per second.

(vii) Recalculate the maximum speed per paragraph (c)(2) (i) or (ii) of this section using the measured rated speed derived from the new maximum torque curve. If the new maximum speed lies outside the range of speeds encompassed by the actual map, then the map shall be considered void. The entire mapping procedure shall be repeated, using the newly derived measured rated speed in all calculations.

(viii) For warm engines, the entire warm-up procedure specified in paragraphs

(d)(3) (i) through (iv) of this section need not be repeated. It is sufficient for an engine already at normal operating temperatures to be operated per the requirements of paragraph (d)(3)(iv) of this section, after which the procedures of paragraph (d)(3) (v) through (vi) of this section may be performed.

(e) Mapping curve generation.

(1) Otto-cycle engines. (i) Fit all data points recorded under paragraphs (d)(2) (vi) and (vii) of this section (100 rpm increments) with a cubic spline, Akima, or other technique approved in advance by the Administrator. The resultant curve shall be accurate to within  $\pm 1.0$  ft-lbs of all recorded engine torques.

(ii) All points generated under the continuous rpm sweep by paragraphs (d)(2) (vi) and (viii) of this section shall be connected by linear interpolation between points.

(iii) For governed engines, all points above the maximum speed (see paragraph (c)(1)(ii) of this section) shall be assigned maximum torque values of zero for purposes of cycle generation.

(iv) For all engines, all speed points below the minimum speed shall be assigned a maximum torque value equal to that observed at minimum speed for purposes of cycle generation.

(v) The torque curve resulting from paragraphs (e)(1) (i) through (iv) of this section is the mapping curve and will be used to convert the normalized torque values in the engine cycle (see paragraph (f)(1) of appendix I to this part) to actual torque values for the test cycle.

(2) Diesel engines. (i) Connect all data points recorded under paragraph (d)(3)(vi) of this section using linear interpolation between points.

(ii) For governed engines, all points above the maximum speed (see paragraph (c)(2)(ii) of this section) shall be assigned maximum torque values of zero for purposes of cycle generation.

(iii) For all engines, all speed points below the minimum speed shall be assigned a maximum torque value equal to that observed at the minimum speed for purposes of cycle generation.

(iv) The torque curve resulting from paragraphs (e)(2) (i) through (iii) of this section is the mapping curve and will be used to convert the normalized torque values in the engine cycle (see paragraph (f)(2) of appendix I to this part) into actual torque values for the test cycle.

(f) Alternate mapping. If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine or engine family, alternate mapping techniques may be used. These alternate techniques must satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this section for reasons of safety or representativeness shall be reported per §86.1344(e)(6), along with the justification for their use. In no case, however, shall descending continual sweeps of rpm be used for governed or turbocharged engines.

(g) Replicate Tests. An engine need not be mapped before each and every cold cycle test. An engine shall be remapped prior to a cold cycle test if:

(1) An unreasonable amount of time has transpired since the last map, as determined by engineering judgment, or

(3) Physical changes or recalibrations have been made to the engine which may potentially affect engine performance.

#### **§ 1065.515 Test cycle generation.**

(a) *Denormalizing test cycles.* The standard-setting parts establish the applicable test cycles consisting of second-by-second specifications for normalized torque and speed for transient cycles, or modal specifications for normalized torque and speed (or power and speed) for steady-state cycles. You must denormalize these values to get actual torque and speed for your engine.

(1) Torque is normalized to a maximum-torque value. Check the standard-setting part to see if it is normalized based on the maximum torque at the given speed or based on the maximum torque for all speeds. To

denormalize the torque values in the cycle, use the engine's maximum-torque point or its torque map (§ 1065.510 describes how to generate the torque map).

(2) Power is normalized to a maximum-power value. Check the standard-setting part to see if it is normalized based on the maximum power at the given speed or based on the maximum power for all speeds. To denormalize the power values in the cycle, use the engine's maximum-power point or its power map (§ 1065.510 describes how to generate the power map).

(3) To denormalize speed, use the following equation:

Actual engine speed =  $(0.01) \times (\% \text{engine speed}) \times (\text{Maximum test speed} - \text{warm idle speed}) + \text{warm idle speed}$

(4) Paragraph (d) of this section describes how to calculate maximum test speed.

(b) *Example of denormalizing a test points.* For an engine with maximum test speed of 3800 rpm and warm idle speed of 600 rpm, denormalize the following test point: percent engine speed = 43, percent torque = 82.

(1) *Calculate actual engine speed.* The following equation applies for this example:

Actual engine speed =  $(0.01) \times (43) \times (3800 - 600) + 600 = 1976$  rpm.

(2) *Determine actual torque.*

Determine the maximum observed torque at 1976 rpm from the maximum torque curve. Then multiply this value (for example, 358 ft-lbs.) by 0.82. The resulting actual torque is 294 ft-lbs.

(c) *Cold-start enhancement devices.* If an engine has a properly operating automatic enhancement device for cold starts, let it override the zero-percent speed specified in the test cycles.

(d) *Maximum test speed.* For constant-speed engines, maximum test speed is the same as the engine's maximum operating speed in use. Maximum test speed for variable-speed engines occurs on the lug curve at the point farthest from the origin on a plot of power vs. speed. To find this speed, follow three main steps:

(1) *Generate the lug curve.* Before testing an engine for emissions, generate data points for maximum

measured brake power with varying engine speed (see § 1065.510). These data points form the lug curve.

(2) *Normalize the lug curve.* To normalize the lug curve, do three things:

(i) Identify the point (power and speed) on the lug curve where maximum power occurs.

(ii) Normalize the power values of the lug curve—divide them by the maximum power and multiply the resulting values by 100.

(iii) Normalize the engine speed values of the lug curve—divide them by the speed at which maximum power occurs and multiply the resulting values by 100.

(3) *Determine maximum test speed.* Calculate the maximum test speed from the following speed-factor analysis:

(i) For a given power-speed point, the speed factor is the normalized distance to the power-speed point from the zero power, zero-speed point. Compute the speed factor's value:

$$\text{Speed factor} = \sqrt{(\text{power})^2 + (\text{speed})^2}$$

(ii) Determine the maximum value of speed factors for all the power-speed data points on the lug curve. Maximum test speed is the speed at which the speed factor's maximum value occurs. Note that this maximum test speed is the 100-percent speed point for normalized transient duty cycles.

(e) *Intermediate test speed.* Determine intermediate test speed with the following provisions:

(1) If peak torque speed is 60 to 75 percent of the maximum test speed, the intermediate speed point is at that same speed.

(2) If peak torque speed is less than 60 percent of the maximum test speed, the intermediate speed point is at 60 percent of maximum test speed.

(3) If peak torque speed is greater than 75 percent of the maximum test speed, the intermediate speed point is at 75 percent of maximum test speed.

#### Transient test cycle generation.

(a) The heavy-duty transient engine cycles for Otto-cycle and diesel engines are listed in appendix I ((f) (1), (2) and (3)) to this part. These second-by-second listings represent torque and rpm maneuvers characteristic of heavy duty engines. Both rpm and torque are normalized (expressed as a percentage of maximum) in these listings.

(1) To unnormalize rpm, use the following equation:

$$\text{Actual rpm} = \frac{\% \text{ rpm (Measured rated rpm} - \text{Curb idle rpm)}}{100} + \text{Curb idle rpm}$$

The method of calculating measured rated rpm is detailed in paragraph (g) of this section.

(2) Torque is normalized to the maximum torque at the rpm listed with it.

Therefore, to unnormalize the torque values in the cycle, the maximum torque curve for the engine in question must be used.

(3) The EPA Engine Dynamometer Schedules for Heavy Duty Diesel Engines are listed in the respective standard setting part. (f)(2) contains torque points referred to as “closed rack motoring.” For reference cycle calculation torque points shall take on unnormalized values determined in either of the following three ways:

(i) Negative 40 percent of the positive torque available at the associated speed point.

(ii) Map the amount of negative torque required to motor the engine between idle and maximum mapping speed and use this map to determine the amount of negative torque required at the associated speed point.

(iii) Determine the amount of negative torque required to motor the engine at idle and rated speeds and linearly interpolate using these two points.

(b) Example of the unnormalization procedure.

The following test point shall be unnormalized:

<u>Percent</u>	<u>Percent</u>
<u>RPM</u>	<u>Torque</u>
<u>43</u>	<u>82</u>

Given the following values:

Measured Rated rpm = 3800.

Curb Idle rpm = 600.

(1) Calculate actual rpm:

$$\text{Actual rpm} = \frac{\% \text{ rpm (measured rated rpm} - \text{curb idle rpm)}}{100} + \text{curb idle rpm}$$

$$= \frac{43 (3800 - 600)}{100} + 600$$

$$= \frac{43 (3800 - 600)}{1976} + 600$$

(2) Determine actual torque: Determine the maximum observed torque at 1976 rpm from the maximum torque curve. Then multiply this value (e.g., 358 ft-lbs) by 0.82. This results in an actual torque of 294 ft-lbs.

(c) Engine speed and torque shall be recorded at least once every second during the cold start test and hot start test. The torque and rpm feedback signals may be filtered.

(d) Idle Speed Enhancement Devices (e.g. cold idle, alternator idle, etc.).

For an engine equipped with an idle speed enhancement device, the zero percent speed specified in the engine dynamometer schedules does not apply. The idle speed shall be the speed that results from the proper operation of the engine’s idle speed enhancement device.

(1) During idle speed enhancement device operation, a manual transmission engine shall be allowed to idle at whatever speed is required to target a feedback torque equal to zero (using, for example, clutch disengagement, speed to torque control switching, software overrides, etc.) at those points in appendix I(f)(1), (f)(2), or (f)(3) to this part where both reference speed and reference torque are zero percent values. For each idle segment that is ten seconds or longer, the average feedback torque must be within ±10 ft-lbs of zero.

To allow for transition, up to the first four seconds may be deleted from each idle segment calculation.

(2) During idle speed enhancement device operation, an automatic transmission engine shall be allowed to idle at whatever speed is required to target a feedback torque equal to CITT (see paragraph (e)(2) of this section for definition of CITT) at those points where both reference speed and reference torque are zero percent values. For each idle segment that is ten seconds or longer, the average feedback torque must be within ±10 ft-lbs of CITT. To allow for transition, up to the first four seconds may be deleted from each idle segment calculation.

(e) Automatic transmissions. The reference cycles shall be altered for test engines intended primarily for use with automatic transmissions.

(1) Zero percent speed for automatic transmission engines is defined as curb idle rpm (i.e., in-vehicle, coupled with automatic transmission in gear).

(2) All zero-percent speed, zero-percent torque points (idle points) shall be modified to zero percent speed, Curb Idle Transmission Torque (CITT). Also, all points with speed equal to or less than zero percent and torque less than CITT shall be modified to CITT. Motoring torque shall remain unchanged. In order to provide a smooth torque transition, all consecutive torque points that are between 0 and CITT shall be changed to CITT if the first of these is preceded or the last of these is succeeded by idle points. The manufacturer's specified CITT shall be based upon that value observed in typical applications at the mean of the manufacturers' specified idle speed range at stabilized temperature conditions.

(f) Clutch operation. Manual transmission engines may be tested with a clutch. If used, the clutch shall be disengaged at all zero percent speeds, zero percent torque points, but may be engaged up to two points preceding a non-zero point, and may be engaged for time segments with zero percent speed and torque points of durations less than four seconds.

(g) Measured rated rpm. The measured rated rpm corresponds to the 100 percent rpm values specified in the reference cycles (paragraphs (f) (1) and (2) of appendix I to this part). It is generally intended to represent the rpm at which maximum brake horsepower occurs. For the purposes of this test sequence, it shall either be defined as the manufacturer's specified rated speed, or calculated in the following way, whichever yields the higher speed:

(1) From the maximum torque curve generated, find the maximum observed brake horsepower of the engine.

(2) Calculate 98 percent of the observed maximum brake horsepower, and determine from the maximum torque curve the highest and lowest engine rpms at which this brake horsepower is observed.

(3) The highest and lowest of the 98 percent power rpms represent the endpoints of an rpm range. The midpoint of this range shall be considered the measured rated rpm for cycle generation purposes.

#### **Supplemental emission test; test cycle and procedures.**

The test procedures of this subpart N apply for supplemental emission testing, except as specified otherwise in this section.

(a) Applicability. This section applies to 2007 and later diesel heavy duty engines.

(b) Test cycle. (1)(i) The following 13-mode cycle must be followed in dynamometer operation on the test engine:

Mode number	Engine speed	Percent load	Weighting factor	Mode length (minutes)
1 .....	Idle	.....	0.15	4
2 .....	A	100	0.08	2
3 .....	B	50	0.10	2
4 .....	B	75	0.10	2
5 .....	A	50	0.05	2
6 .....	A	75	0.05	2
7 .....	A	25	0.05	2
8 .....	B	100	0.09	2
9 .....	B	25	0.10	2
10 .....	C	100	0.08	2
11 .....	C	25	0.05	2
12 .....	C	75	0.05	2
13 .....	C	50	0.05	2

(ii) Upon Administrator approval, the manufacturer may use mode lengths other than those listed in paragraph (b)(1)(i) of this section.

(2) In addition to the 13 test points identified in paragraph (b)(1) of this section, for engines not certified to a NOX standard or FEL less than 1.5 g/bhp-hr, EPA may select, and require the manufacturer to conduct the test using, up to 3 additional test points within the control area (as defined in paragraph (e) of this section). EPA will notify the manufacturer of these supplemental test points in writing in a timely manner before the test. Emissions sampling for the additional test modes must include all regulated gaseous pollutants. Particulate matter does not need to be measured.

(c) Determining engine speeds. (1) The engine speeds A, B and C, referenced in the table in paragraph (b)(1) of this section, and speeds D and E, referenced in § 86.1380, must be determined as follows:

$$\text{Speed A} = n_{lo} + 0.25 \times (n_{hi} - n_{lo})$$

$$\text{Speed B} = n_{lo} + 0.50 \times (n_{hi} - n_{lo})$$

$$\text{Speed C} = n_{lo} + 0.75 \times (n_{hi} - n_{lo})$$

$$\text{Speed D} = n_{hi}$$

$$\text{Speed E} = n_{lo} + 0.15 \times (n_{hi} - n_{lo})$$

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Where:

n<sub>hi</sub> = High speed as determined by calculating 70% of the maximum power. The highest engine speed where this power value occurs on the power curve as defined as n<sub>hi</sub>.

n<sub>lo</sub> = Low speed as determined by calculating 50% of the maximum power. The lowest engine speed where this power value occurs on the power curve is defined as n<sub>lo</sub>.

Maximum power = the maximum observed power calculated according to the engine mapping procedures defined in § 86.1332.

(d) Determining engine torques

Determine engine torques as per §86.1333-90. Provisions for automatic transmissions in §86.1333-90 are applicable to this test procedure.

(e) Determining the control area. The control area extends from the engine speed A to C, as defined in paragraph (c) of this section, and extends from 25 to 100 percent load.

(f) Test requirements—(1) Engine and sampling system preconditioning.

Prior to beginning the test sequence, the engine and sampling system must be preconditioned using the following procedure.

(2) If the engine is cold, start and operate the engine at curb idle for 2 to 3 minutes and then at approximately 50 percent power at peak-torque speed for 5 to 7 minutes. Then sampling system preconditioning may proceed immediately as per (f)(5) of this section.

(3) If the engine is has completed a hot-start portion of the applicable transient test cycle within the past 20 minutes, sampling system preconditioning may proceed immediately as per (f)(5) of this section.

(4) If the engine is already running and its oil and water temperatures are stabilized such that the temperatures are maintained within 10 percent of point for 2 minutes, sampling system preconditioning may proceed immediately as per (f)(5) of this section.

(5) To precondition the sampling system, operate the engine at a condition of rated-speed, 100 percent torque for a minimum of 20 minutes while simultaneously operating the CVS and secondary dilution system and taking particulate matter emissions samples from the secondary dilution tunnel. Particulate sample filters need not be stabilized or weighed, and may be discarded. Filter media may be changed during conditioning as long as the total sampling time through the filters and sampling system is at least 20 minutes. Flow rates shall be set at the approximate flow rates selected for SET testing. Torque shall be reduced from 100 percent torque while maintaining the rated speed condition as necessary to prevent exceeding 191 °C at the primary dilution tunnel sampling zone. However, sufficient torque shall be maintained to prevent condensation at any point in the dilution tunnel.

(6) After completing (f)(5) of this section, operate the engine at curb idle at 0 or CITT. The test sequence must be started within 5 minutes after completion of the sampling system preconditioning specified in (f)(5) of this section.

(7) Test sequence for engines not certified to a NO<sub>x</sub> standard or FEL less than 1.5 g/bhp-hr. The test must be performed in the order of the mode numbers in paragraph (b)(1) of this section. The EPA-selected test points identified under paragraph (b)(2) of this section must be performed immediately upon completion of mode 13. The engine must be operated for the prescribed time in each mode, completing engine speed and load changes in the first 20 seconds of each mode. The specified speed must be held to within ±50 rpm and

the specified torque must be held to within plus or minus two percent of the maximum torque at the test speed.

(8) Test sequence for engines certified to a NO<sub>x</sub> standard or FEL less than 1.5 g/bhp-hr. The SET cycle tabulated in CFR 40 Part 86 Appendix 1 (f)(4) shall be followed, and the test cycle validation criteria specified in §86.1341-98 must be met, and the following steps shall be taken for each test when testing an on-highway engine:

(i) Prepare the engine, dynamometer, and sampling system.

(ii) Change filters, etc., and leak check as necessary.

(iii) Connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems if bag sampling is used.

(iv) Attach the CVS to the engine exhaust system any time prior to starting the CVS.

(v) Start the CVS (if not already on), the sample pumps, as applicable, the engine cooling fan(s), and the data collection system. The heat exchanger of the constant volume sampler (if used), and the heated components of any continuous sampling system(s) (if applicable) shall be preheated to their designated operating temperatures before the test begins. (See § 86.1340(e) for continuous sampling procedures.)

(vi) Adjust the sample flow rates to the desired flow rates and set the CVS gas flow measuring devices to zero. CFV-CVS sample flow rate is fixed by the venturi design.

(vii) For engines tested for particulate emissions, carefully install a clean, loaded particulate sample filter cartridge into the filter holder assembly. It is recommended that this be done within the filter stabilization environment, with both ends of the filter holder assembly plugged during transport to the emissions test facility. Install the assembled filter holder into the sample flow line.

(viii) With the engine already running as per (f)(5) of this section simultaneously begin exhaust and dilution air sampling at the start of the SET test cycle specified in Part 86 Appendix 1 (f)(4). At this same time turn on the hydrocarbon and NO<sub>x</sub> (and CO and CO<sub>2</sub>, if continuous) analyzer system integrators (if used), and turn on the particulate sample pumps and indicate the start of the test on the data collection medium.

(ix) During particulate sampling it must be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than  $\pm 5.0$  percent of its set point value. Sample flow is the net difference between the flow rate through the sample filters and the secondary dilution air flow rate.

(x) Record flow. If the set flow rate cannot be maintained because of high particulate loading on the filter, the test shall be terminated. The test shall be rerun using a lower sample flow rate or greater dilution.

(xi) On the last record of the cycle, allow sampling system response times to elapse and cease sampling. Turn off the particulate sample pump(s) (if appropriate), the gas flow measuring device(s) and any continuous analyzer system integrator and indicate the end of the test on the data collection medium.

(xii) As soon as possible, transfer the exhaust and dilution air bag samples to the analytical system and process the samples according to § 86.1340. A stabilized reading of the exhaust sample on all analyzers shall be obtained within 20 minutes of the end of the sample collection phase of the test. For particulate measurements, carefully remove the filter holder assembly. It is recommended that the filter cartridge be transferred to and from the filter stabilization environment within the filter holder assembly with both ends plugged, and that the cartridge be removed from the filter holder assembly within the stabilization environment. Transfer the particulate filter to the stabilization environment for post-test stabilization. Filters may be stabilized in the petri dishes while still within the filter cartridges, or the cartridge tops may be removed for stabilization, or the filters may be entirely removed from the filter cartridges and stabilized in the petri dishes alone. Removal of the filters from the filter cartridges shall only take place within the stabilization environment.

(xiii) The CVS and the engine may be turned off, if desired.

(xiv) This procedure is designed for one sample bag for the entire SET test cycle.

(xv) If a dynamometer test run is determined to be void, corrective action may be taken. Provisions for corrective action for the hot start and hot cycle portions of the transient test may be applied as per 86.1336-84.

(9) Particulate sampling. (i) For engines not certified to a NO<sub>x</sub> standard or FEL less than 1.5 g/bhp-hr, one filter shall be used for sampling PM over the 13-mode test procedure. The modal weighting factors specified in paragraph (b)(1) of this section shall be taken into account by taking a sample proportional to the exhaust mass flow during each individual mode of the cycle. This can be achieved by adjusting sample flow rate, sampling time, and/or dilution ratio, accordingly, so that the criterion for the effective weighting factors is met. The sampling time per mode must be at least 4 seconds per .01 weighting factor. Sampling

must be conducted as late as possible within each mode. Particulate sampling shall be completed no earlier than 5 seconds before the end of each mode.

(ii) For engines certified to a NO<sub>x</sub> standard or FEL less than 1.5 g/bhp-hr, one filter shall be used for sampling PM over the SET cycle tabulated in CFR 40 Part 86 Appendix 1 (f)(4). PM sampling for the SET test cycle shall be conducted as per §86.1310-2007 and PM filter handling shall be conducted as per §86.1312-2007.

(10) The test must be conducted with all emission-related engine control variables in the highest brake-specific NO<sub>x</sub> emissions state which could be encountered for a 30 second or longer averaging period at the given test point and for the conditions under which the engine is being tested.

(11) Exhaust emissions measurements and calculations. Manufacturers must follow the exhaust emissions sample analysis procedures under § 86.1340, and the calculation formulas and procedures under § 86.1342, for the 13-mode cycle, the 3 EPA-selected test points, and the SET cycle specified in Part 86 Appendix 1 (f)(4), as applicable, including the NO<sub>x</sub> correction factor for humidity.

(12) Calculating the weighted average emissions for engines not certified to a NO<sub>x</sub> standard or FEL less than 1.5 g/bhp-hr.

(i) For each regulated gaseous pollutant, the weighted average emissions must be calculated as follows:

$$A_{WA} = \frac{\sum_{i=1}^n [A_{Mi} \times WF_i]}{\sum_{i=2}^n [A_{Pi} \times WF_i]}$$

Where:

AWA = Weighted average emissions for each regulated gaseous pollutant, in grams per brake horse-power hour.

AM = Modal average mass emissions level, in grams per hour. Mass emissions must be calculated as described in § 86.1342.

AP = Modal average power, in brake horsepower. Any power measured during the idle mode (mode 1) is not included in this calculation.

WF = Weighting factor corresponding to each mode of the steady-state test cycle, as defined in paragraph (b)(1) of this section.

i = The modes of the steady-state test cycle, as defined in paragraph (b)(1) of this section.

n = 13, corresponding to the 13 modes of the steady-state test cycle, as defined in paragraph (b)(1) of this section.

(ii) For PM measurements, a single filter must be used to measure PM over the 13 modes. The brake-specific PM emission level for the test must be calculated as described for a transient hot start test in § 86.1343. Only the power measured during the sampling period shall be used in the calculation.

(g) Maximum allowable emission limits.

(1) For gaseous emissions, the 12 non-idle test point results and the four-point linear interpolation procedure specified in paragraph (h) of this section for intermediate conditions, shall define Maximum Allowable Emission Limits for purposes of § 86.007–11(a)(3) except as modified under paragraph (g)(3) of this section. Each engine shall have its own Maximum Allowable Emission Limits generated from the 12 non-idle supplemental steady state test points from that engine. The control area extends from the 25% to the 75% engine speeds, at engine loads of 25% to 100%, as defined in paragraph (e) of this section. Figure 1 of this paragraph (g)(1) depicts a sample Maximum Allowable Emission Limit curve, for illustration purposes only, as follows:

(2) If the weighted average emissions, calculated according to paragraph (f)(6) of this section, for any gaseous pollutant is equal to or lower than required by § 86.007–11(a)(3), each of the 13 test values for that pollutant shall first be multiplied by the ratio of the applicable emission standard (under § 86.007–11(a)(3)) to the weighted average emissions value, and then by 1.10 for interpolation allowance, before determining the Maximum Allowable Emission Limits under paragraph (g)(1) of this section.

(3) If the Maximum Allowable Emission Limit for any point, as calculated under paragraphs (g)(1) and (2) of this section, is greater than the applicable Not-to-Exceed limit (if within the Not-to- Exceed control area defined in § 86.1370–2007(b)), then the Maximum Allowable Emission Limit for that point shall be defined as the applicable Not-to-Exceed limit.

(h) Calculating intermediate test points.

(1) For the three test points selected by EPA under paragraph (b)(2) of this section, the emissions must be measured and calculated as described in paragraph (f)(6)(i) of this section (except that  $n = 1$  and  $WF = 1$ ). The measured values then must be compared to the interpolated values according to paragraph (h)(3) of this

section. The interpolated values are determined from the modes of the test cycle closest to the respective test point according to paragraph (h)(2) of this section.

(2) Interpolating emission values from the test cycle. The gaseous emissions for each regulated pollutant for each of the control points (Z) must be interpolated from the four closest modes of the test cycle that envelop the selected control point Z as shown in Figure 2 of this paragraph (h)(2).

(i) For these modes (R, S, T, U), the following definitions apply:

(A) Speed (R) = Speed(T) = nRT.

(B) Speed (S) = Speed(U) = nSU.

(C) Per cent load (R) = Per cent load (S).

(D) Per cent load (T) = Per cent load (U).

(ii) The interpolated value of the brake specific gaseous emissions of the selected control point Z(EZ) must be calculated as follows:

$$EZ = ERS + (ETU - ERS) * (MZ - MRS) / (MTU - MRS)$$

$$ETU = ET + (EU - ET) * (nZ - nRT) / (nSU - nRT)$$

$$ERS = ER + (ES - ER) * (nZ - nRT) / (nSU - nRT)$$

$$MTU = MT + (MU - MT) * (nZ - nRT) / (nSU - nRT)$$

$$MRS = MR + (MS - MR) * (nZ - nRT) / (nSU - nRT)$$

Where:

ER, ES, ET, EU = for each regulated pollutant, brake specific gaseous emissions of the enveloping modes adjusted according to the factors in(g)(2).

MR, MS, MT, MU = engine torque of the enveloping modes.

MZ = engine torque of the selected control point Z.

nZ = engine speed of the selected control point Z.

(iii) Figure 2 follows:

(3) Comparing calculated and interpolated emission values. The measured brake specific gaseous emissions of the control point Z (XZ) must be less than or equal to the interpolated value (EZ).

(i) Test fuel specifications. The test fuel used for supplemental steady-state testing under this section must meet the requirements of §86.1313.

(i) General requirements. Ambient conditions, charge cooling specifications, and intake and exhaust restrictions for supplemental steady-state testing and maximum allowable emission limit testing under this section must meet the requirements of § 86.1330.

**§ 1065.520 Engine starting, restarting, and shutdown.**

Unless the standard-setting part specifies otherwise, follow the steps in this section to start and shut down the test engine:

(a) *Engine starting.* Start the engine according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer. Use the dynamometer to crank (or motor) the engine at the typical in-use cranking speed with a fully charged battery (nominal speed  $\pm 10$  percent), accelerating the engine to cranking speed in the same time it would take with a starter motor (nominal  $\pm 0.5$  seconds). Stop motoring by the dynamometer within one second of starting the engine. The cycle's free idle period begins when you determine that the engine has started.

(1) If the engine does not start after 15 seconds of cranking, stop cranking and determine the reason it failed to start.

While diagnosing the problem, turn off the device that measures gas flow (or revolution counter) on the constant volume sampler (and all integrators when measuring emissions continuously). Also, turn off the constant-volume sampler or disconnect the exhaust tube from the tailpipe. If failure to start is an operational error, reschedule the engine for testing (this may require soaking the engine if the test requires a cold-start).

(2) If longer cranking times are necessary, you may use them instead of the 15-second limit, as long as the owner's manual and the service-repair manual describe the longer cranking times as normal.

(3) If an engine malfunction causes a failure to start, you may correct it in less than 30 minutes and continue the test.

Reactivate the sampling system at the same time cranking begins. When the engine starts, begin the timing sequence.

If an engine malfunction causes a failure to start, and you cannot restart the engine, the test is void.

(b) *Engine stalling.* Respond to engine stalling as follows:

(1) If the engine stalls during the warm-up period, the initial idle period of test, or the steady-state segment, you may restart the engine immediately using the appropriate starting procedure and continue the test.

(2) If the engine stalls at any other time, the test is void.

(c) *Engine shutdown.* Shut the engine down according to the manufacturer's specifications.

**Engine starting, restarting, and shutdown.**

(a) The engine shall be started according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer. The speed at which the engine is cranked (motored) with the dynamometer shall be equal to the cranking speed (nominal speed  $\pm 10$  percent) in the vehicle with a fully charged battery. The time taken to accelerate the engine to cranking speed by the dynamometer shall be equal (nominal  $\pm 0.5$  seconds) to the time required with a starter motor. Motoring by the dynamometer shall be terminated not more than one second after the engine starts. The 24  $\pm 1$ -second free idle period, and declutching if applicable, shall begin when the engine is determined to have started.

(1) Engines equipped with automatic chokes shall be operated according to the manufacturer's operating instructions in the owner's manual, including choke setting and "kick-down" from cold fast idle.

(2) Engines equipped with manual chokes shall be operated according to the manufacturer's operating instructions in the owner's manual.

(3) The operator may use the choke, throttle, etc. where necessary to keep the engine running.

(4) If the manufacturer's operating instructions in the owner's manual do not specify a warm engine starting procedure, the engine (automatic and manual choke engines) shall be started by depressing the throttle half way and cranking the engine until it starts.

(b)(1) If the engine does not start after 15 seconds of cranking, cranking shall cease and the reason for failure to start shall be determined. The gas flow measuring device (or revolution counter) on the constant

volume sampler (and the hydrocarbon integrator when testing diesel-fueled engines) shall be turned off during this diagnostic period. In addition, either the CVS should be turned off or the exhaust tube disconnected from the tailpipe during the diagnostic period. If failure to start is an operational error, the engine shall be rescheduled for testing from a cold start.

(2) If longer cranking times are necessary and recommended to the ultimate purchaser, such cranking times may be used in lieu of the 15-second limit, provided the owner's manual and the service repair manual indicate that the longer cranking times are normal.

(3) If a failure to start occurs during the cold portion of the test and is caused by an engine malfunction, corrective action of less than 30 minutes duration may be taken, and the test continued. The sampling system shall be reactivated at the same time cranking begins. When the engine starts, the timing sequence shall begin. If failure to start is caused by engine malfunction and the engine cannot be started, the test shall be voided and corrective action may be taken.

(4) If a failure to start occurs during the hot start portion of the test and is caused by engine malfunction, the engine must be started within one minute of key on. The sampling system shall be reactivated at the same time cranking begins. When the engine starts, the transient engine cycle timing sequence shall begin. If the engine cannot be started within one minute of key on, the test shall be voided, corrective action taken, and the engine rescheduled for testing.

(c) Engine stalling. (1) If the engine stalls during the initial idle period of either the cold or hot start test, the engine shall be restarted immediately using the appropriate cold or hot starting procedure and the test continued.

(2) If the engine stalls anywhere in the cold cycle, except in the initial idle period, the test shall be voided.

(3) If the engine stalls on the hot cycle portion of the test at any time other than the initial idle, the engine may be shut off and resoaked for 20 minutes. The hot cycle may then be rerun. Only one hot start soak and restart is permitted.

(d) Engine shutdown. Engine shutdown shall be performed in accordance with manufacturer's specifications.

(e) Test equipment malfunction—(1) Gasoline- and methanol-fueled engines. If a malfunction occurs in any of the required test equipment during the test run, the test shall be voided.

(2) Diesel-fueled, natural gas-fueled and liquefied petroleum gas-fueled engines. (i) If a malfunction occurs in any of the required test equipment during the cold cycle portion of the test, the test shall be voided.

(ii) If a malfunction occurs in any of the required test equipment (computer, gaseous emissions analyzer, etc.) during the hot cycle portion of the test, complete the full engine cycle before engine shut-down then resoak for 20 minutes.

(A) If the test equipment malfunction can be corrected before the resoak period has been completed, the hot cycle portion of the test may be rerun.

(B)(1) If the test equipment malfunction is corrected after the completion of the resoak period, then the preconditioning cycle must be run before the hot cycle. This consists of a full 20 minute transient cycle followed by a 20 minute soak and then the for-record hot cycle.

(2) In no case can the start of the cold cycle and the start of the hot cycle be separated by more than 4 hours.

## **§ 1065.525 Engine dynamometer test run.**

(a)(1) Before any cold soak or cool down:

(i) Final calibration of the dynamometer and throttle control systems may be performed. These calibrations may consist of steady-state operations and/or actual practice cycle runs, and must be completed before sampling system preconditioning (if applicable).

(ii) Conduct sampling system preconditioning for diesel engines (optional for model years prior to 2007 (2009 for nonroad)) by operating the engine at a condition of rated-speed, 100 percent torque for a minimum of 20 minutes while simultaneously operating the CVS and secondary dilution system and taking particulate matter emissions samples from the secondary dilution tunnel. Particulate sample filters need not be stabilized or weighed, and may be discarded. Filter media may be changed during conditioning as long as the total sampled time through the filters and sampling system exceeds 20 minutes. Flow rates shall be set at the approximate flow rates selected for transient testing. Torque shall be reduced from 100 percent torque

while maintaining the rated speed condition as necessary to prevent exceeding the maximum sample zone temperature specifications.

(2) Following sampling system preconditioning cycle, the engine shall be cooled as allowed.

(f)(2) Exhaust aftertreatment device cool-down may be accomplished in whatever manner and using whatever coolant deemed appropriate by proper engineering judgment. The aftertreatment device, engine, and exhaust piping configurations also may be separated, but only for the purpose of flowing clean air through the exhaust path within the aftertreatment device. The clean air flow direction must be in the normal direction of exhaust flow within the aftertreatment device. The clean air temperature must be at least 15 degrees C.

(a) The following steps shall be taken for each test when testing an on-highway engine:

(1) Prepare for the cold-start test.

(ii) Prepare the engine, dynamometer, and sampling system.

(iii) Change filters, etc., and leak check as necessary.

(2) Connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems if bag sampling is used.

(4) Attach the CVS to the engine exhaust system any time prior to starting the CVS.

(5) Start the CVS (if not already on), the sample pumps (except for the particulate sample pump(s), if applicable), the engine cooling fan(s), and the data collection system. The heat exchanger of the constant volume sampler (if used), and the heated components of any continuous sampling system(s) (if applicable) shall be preheated to their designated operating temperatures before the test begins.

(6) Adjust the sample flow rates to the desired flow rates and set the CVS gas flow measuring devices to zero. CFV-CVS sample flow rate is fixed by the venturi design.

(7) For engines tested for particulate emissions, carefully install a clean, loaded particulate sample filter cartridge into the filter holder assembly. It is recommended that this be done within the filter stabilization environment, with both ends of the filter holder assembly plugged during transport to the emissions test facility. Install the assembled filter holder into the sample flow line.

(8) Follow the manufacturer's instructions for starting. Simultaneously start the engine and begin exhaust and dilution air sampling. For petroleum-fueled diesel engines turn on the hydrocarbon and NO<sub>x</sub> (and CO and CO<sub>2</sub>, if continuous) analyzer system integrators (if used), and turn on the particulate sample pumps and indicate the start of the test on the data collection medium.

(9) Allow the engine to idle freely with no-load for 24±1 seconds as per the applicable test cycle. This idle period for automatic transmission engines may be interpreted as an idle speed in neutral or park. All other idle conditions shall be interpreted as an idle speed in gear. It is permissible to lug the engine down to curb idle speed during the last 8 seconds of the free idle period for the purpose of engaging dynamometer control loops.

(10) Begin the transient engine cycles such that the first non-idle record of the cycle occurs at 25±1 seconds. The applicable test cycles' free idle time is included in the 25±1 seconds.

(i) During particulate sampling it must be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ±5.0 percent of its set point value (except for the first 10 seconds of sampling). Sample flow is the net difference between the flow rate through the sample filters and the secondary dilution air flow rate.

(ii) Record flow. If the set flow rate cannot be maintained because of high particulate loading on the filter, the test shall be terminated. The test shall be rerun using a lower sample flow rate or greater dilution.

(11) On the last record of the cycle, cease sampling. Immediately turn the engine off and start a hot-soak timer. . Also turn off the particulate sample pumps, the gas flow measuring device(s) and any continuous analyzer system integrator and indicate the end of the test on the data collection medium. Continuous emissions sampling systems should continue to sample after the end of the test cycle until system response times have elapsed.

(12) Immediately after the engine is turned off, turn off the engine cooling fan(s) if used. As soon as possible, transfer the "cold start cycle" exhaust and dilution air bag samples to the analytical system and process the samples. A stabilized reading of the exhaust sample on all analyzers shall be obtained within 20 minutes of the end of the sample collection phase of the test. (13) Allow the engine to soak if cycle indicates

(14) Prepare the engine and dynamometer for the hot start test if cycle indicates.

(156) Connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems.

(17) Start the sample pumps (except the particulate sample pump(s), if applicable), the engine cooling fan(s) and the data collection system. The heat exchanger of the constant volume sampler (if used) and the heated components of any continuous sampling system(s) (if applicable) shall be preheated to their designated operating temperatures before the test begins. See § 86.1340(e) for continuous sampling procedures.

(18) Adjust the sample flow rates to the desired flow rate and set the CVS gas flow measuring devices to zero.

(19) For diesel engines tested for particulate, carefully install a clean, loaded particulate sample filter cartridge in the filter holder assembly and install the filter holder assembly in the sample flow line.

(20) Follow the manufacturer's choke and throttle instruction for hot starting. Simultaneously start the engine and begin exhaust and dilution air sampling. For diesel engines, turn on the hydrocarbon and NO<sub>x</sub> (and CO and CO<sub>2</sub>, if continuous) analyzer system integrator (if used), indicate the start of the test on the data collection medium, and turn on the particulate sample pump(s).

(22) Allow the engine to idle freely with no-load for 24±1 seconds. The provisions and interpretations of paragraph (a)(9) of this section apply.

(23) Begin the transient-engine cycle such that the first non-idle record of the cycle occurs at 25±1 seconds. The free idle is included in the 25±1 seconds.

(24) On the last record of the cycle, allow sampling system response times to elapse and cease sampling. Turn off the particulate sample pump(s) (if appropriate), the gas flow measuring device(s) and any continuous analyzer system integrator and indicate the end of the test on the data collection medium.

(25) As soon as possible, transfer the "hot start cycle" exhaust and dilution air bag samples to the analytical system and process the samples. A stabilized reading of the exhaust sample on all analyzers shall be obtained within 20 minutes of the end of the sample collection phase of the test. For particulate measurements, carefully remove the filter holder assembly. It is recommended that the filter cartridge be transferred to and from the filter stabilization environment within the filter holder assembly with both ends plugged, and that the cartridge be removed from the filter holder assembly within the stabilization environment. Transfer the particulate filter to the stabilization environment for post-test stabilization. Filters may be stabilized in the petri dishes while still within the filter cartridges, or the cartridge tops may be removed for stabilization, or the filters may be entirely removed from the filter cartridges and stabilized in the petri dishes alone. Removal of the filters from the filter cartridges shall only take place within the stabilization environment.

(26) The CVS and the engine may be turned off, if desired.

(b) The procedure in paragraph (a) of this section is designed for one sample bag for the cold start portion and one for the hot start portion.

(c) If a dynamometer test run is determined to be void, corrective action may be taken. The engine may then be allowed to cool (naturally or forced) and the dynamometer test rerun.

Take the following steps for each test: (a) Prepare the engine, dynamometer, and sampling system. Change filters or other replaceable items and check for leaks as necessary.

(b) If you are using bag samples, connect evacuated sample-collection bags to the collection system for the dilute exhaust and dilution air sample. (c) Attach the CVS to the engine's exhaust system any time before starting the CVS.

(d) Start the CVS (if not already started), the sample pumps, the engine cooling fans, and the data-collection system. Before the test begins, preheat the CVS's heat exchanger (if used) and the heated components of any continuous sampling systems to designated operating temperatures.

(e) Adjust the sample flow rates to the desired levels and set to zero the devices in the CVS that measure gas flow. The venturi design fixes the sample flow rate in a CFV-CVS.

(f) Start the engine if engine starting is not part of the test cycle, as specified in the standard-setting part.

(g) Run the test cycle specified in the standard-setting part and collect the test data.

(h) As soon as practical after the test cycle is complete, analyze the bag samples.

#### **§ 1065.530 Test cycle validation criteria.**

(a) *Steady-state emission testing.*

Make sure your engine's speeds and loads stay within ±2 percent of the set point during the sampling period.

(b) *Transient emission testing performed by EPA.* Emission tests must meet the specifications of this paragraph (b). Otherwise, they do not comply with the test cycle requirements of the standard-setting part,

unless we determine the cause of the failure to meet these specifications is related to the engine rather than the test equipment.

(1) *Shifting feedback signals.* The time lag between the feedback and reference cycle values may bias results. To reduce this effect, you may advance or delay the entire sequence of engine-speed and torque-feedback signals with respect to the reference sequence for speed and torque. If you shift the feedback signals, you must shift speed and torque the same amount in the same direction.

(2) *Calculating brake kilowatt-hour emissions.* Calculate brake kilowatt-hour emissions for each pair of feedback values recorded for engine speed and torque. Also calculate the reference brake kilowatt-hour for each pair of reference values for engine speed and torque. Calculate to five significant figures.

(3) *Performing regression-line analysis.* Perform regression analysis to calculate validation statistics as follows:

(i) Perform linear regressions of feedback value on reference value for speed, torque, and brake power on 1 Hz data after the feedback shift has occurred (see paragraph (b)(1) of this section). Use the method of least squares, with the best-fit equation having the form:

$$y = mx + b$$

Where:

y = The feedback (actual) value of speed (rpm), torque (ft-lbs.), or brake power.

m = Slope of the regression line.

x = The reference value (speed, torque, or brake power).

b = The y-intercept of the regression line.

(ii) Calculate the standard error of estimate (SE) of y on x and the coefficient of determination ( $r^2$ ) for each regression line.

(iii) For a valid test, make sure the feedback cycle's integrated brake kilowatt-hour is within 5 percent of the reference cycle's integrated brake kilowatt-hour. Also, ensure that the slope, intercept, standard error, and coefficient of determination meet the criteria in the following table (you may delete individual points from the regression analyses, consistent with good engineering judgment):

TABLE 1 OF § 1065.530.—STATISTICAL CRITERIA FOR VALIDATING TEST CYCLES

	Speed	Torque	Power
1. Slope of the regression line (m)	0.980 to 1.020 .....	0.880 to 1.030 .....	0.880 to 1.030.
2. Y intercept of the regression line (b).	$ b  \leq 40$ rpm .....	$ b  \leq 5.0$ percent of maximum torque from power map.	$ b  \leq 3.0$ percent of maximum torque from power map.
3. Standard error of the estimate of Y on X (SE).	100 rpm .....	15 percent of maximum torque from power map.	10 percent of maximum power from power map.
4. Coefficient of determination ( $r^2$ )	$r^2 \geq 0.970$ .....	$r^2 \geq 0.900$ .....	$r^2 \geq 0.900$ .

(c) *Transient testing performed by manufacturers.* Emission tests that meet the specifications of paragraph (b) of this section satisfy the standard-setting part's requirements for test cycles. You may ask to use a dynamometer that cannot meet those specifications, consistent with good engineering practice. We will approve your request as long as using the alternate dynamometer does not affect your ability to show that you comply with all applicable emission standards.

#### **§1065.535 Particulate mass test procedures**

(c) Particulate matter filter handling and weighing. Care should be taken to prevent contamination of the sample filters and to prevent a buildup of static charge on the filters that could interfere with filter weighing. Static neutralizers, such as Po-210 sources, shall be used to neutralize charge on a filter prior to each weighing. The static neutralizer must be grounded with respect to the microbalance. A static neutralizer should be replaced at the interval recommended by its manufacturer, or when it is no longer able to reduce static charge on a filter to less than  $\pm 2$  VDC as measured with an electrostatic monitor at the microbalance workstation. The person weighing filters shall be grounded with respect to the microbalance to prevent imparting a static charge on the filters. This can be accomplished safely by using a grounding strap such as the wrist straps that are commonly used in the microelectronics industry, or by connecting a similar grounding strap to the tweezers. To prevent electrical shock, a 1-megohm resistor should be installed in series between the person weighing filters and ground.

(1) Within the filter stabilization environment, a pair of clean and electrically conductive tweezers shall be used to place a filter in the lower half of a filter cassette and the cassette shall be placed in a partially open glass Petri dish. The dish lid should extend over the filter to prevent gross contamination, but it should be left slightly open on one edge to permit stabilization with the environment for at least 30 minutes (60 minutes for engines of model year earlier than 2007 (2009 for nonroad diesel)).

(2) After at least 30 minutes (60 minutes for engines of model year earlier than 2007 (2009 for nonroad diesel)) of stabilization, each filter shall be weighed using the specified microbalance. The process of weighing a filter may be repeated and a statistical mean weight of a single filter may be calculated. Sound engineering judgment shall dictate the use of statistics to discard outliers and the weighting of averages. Statistical outliers may be discarded, but all results must be reported. If the Administrator determines that the statistical analysis is not consistent with good engineering judgment, he/she may determine compliance from the arithmetic mean of the results. For a clean filter its single weight or statistical mean weight shall be considered the uncorrected tare weight of the filter.

(3) All filter weights shall be corrected for filter buoyancy in air. For the uncorrected tare weight of a filter, this calculated value is the corrected tare weight of the filter, and it must be recorded. Barometric pressure of the microbalance environment shall be measured with an instrument that exhibits  $\pm 0.01\%$  full-scale accuracy and 0.01% per-year full scale stability, and the full-scale value used for such a specification shall not exceed 200 kPa.

(i) Buoyancy correction calculation. (A) Calculate vapor pressure of liquid water using the dewpoint temperature in the Magnus formula:

$$P_w = 0.6113 \times 10^{((7.5 \times T_{dp}) / (237.3 + T_{dp}))}$$

Where:

$P_w$  = vapor pressure of liquid water, kPa.

$T_{dp}$  = dewpoint temperature, °C.

Or calculate the vapor pressure of liquid water using the Wexler and Greenspan equation

(B) Calculate air density using the ideal gas relationship and molecular weights of standard air and water:

$$A = (3.484 \times P - 1.317 \times P_w) / (T + 273.15)$$

Where:

$A$  = air density, kg/m<sup>3</sup>.

$P$  = barometric pressure, kPa.

$P_w$  = vapor pressure of liquid water, kPa.

$T$  = temperature, °C.

(C) Buoyancy correction:

$$M = R \times (1 - (A / \rho_w)) / (1 - (A / \rho_s))$$

Where:

$M$  = corrected mass in units of the balance display.

$R$  = uncorrected filter weight in units of the balance display.

$A$  = calculated air density, kg/m<sup>3</sup>.

$\rho_w$  = density of calibration weight used to calibrate the balance, kg/m<sup>3</sup>.

$\rho_s$  = density of filter material used to sample PM emissions, kg/m<sup>3</sup>.

(ii) For determining  $\rho_s$  note that PTFE (Teflon™) and borosilicate glass both have densities in the range of 2,200 to 2,400 kg/m<sup>3</sup>. Therefore, for PTFE-coated borosilicate glass fiber filters, an acceptable  $\rho_s$  is 2,300 kg/m<sup>3</sup>. Note also that polymethylpentene has a density of 850 kg/m<sup>3</sup>. Because Teflon PTFE membrane filters have an integral polymethylpentene support ring that accounts for 95% of the filter mass, an acceptable  $\rho_s$  for these filters is 920 kg/m<sup>3</sup>. Other  $\rho_s$  values for other filters may be obtained similarly. Information about  $\rho_w$  should be available from the calibration weight manufacturer.

(iii) This paragraph (c)(3)(iii) shows an example of the buoyancy correction. This example assumes the following inputs: barometric pressure ( $P$ ) = 101.325 kPa, temperature ( $T$ ) = 22.0 °C, dewpoint temperature ( $T_{dp}$ ) = 9.5 °C, balance display ( $R$ ) = 100.0000 mg, calibration weight density ( $\rho_w$ ) = 8,000 kg/m<sup>3</sup>, and filter material density ( $\rho_s$ ) = 2,300 kg/m<sup>3</sup>. Then: (A) The water vapor pressure ( $P_w$ ) is calculated as:  $P_w = 0.6113 \times 10^{((7.5 \times 9.5) / (237.3 + 9.5))} = 1.186$  kPa.

(B) The air density ( $A$ ) is calculated as:  $A = (3.484 \times 101.325 - 1.317 \times 1.186) / (22.0 + 273.15) = 1.191$  kg/m<sup>3</sup>.

(C) The corrected mass ( $M$ ) is calculated as:  $M = 100.0000 \times (1 - (1.191 / 8000)) / (1 - (1.191 / 2300)) = 100.0369$  mg.

(4) The uncorrected weight, corrected weight, barometric pressure, temperature and humidity, of the filter shall be recorded. Afterward the filter shall be returned to the lower half of the filter cassette, and the upper half of the cassette shall be set in place. The cassette-with filter-shall then be stored in a covered glass Petri dish or a sealed (i.e., ends plugged) filter holder assembly, either of which shall remain in the filter stabilization environment until needed for testing. It is recommended that the filter be transported between the filter stabilization environment and the location of the emissions test within a sealed filter holder assembly.

(5) After the emissions test, the filter cassette shall be removed from the filter holder assembly. If this removal is performed in the filter stabilization environment, the upper half of the cassette shall be removed using a properly designed separator tool, the lower half of the cassette-with filter-shall be placed in a partially covered Petri dish, and allowed to stabilize for at least 30 minutes (60 minutes for engines of model year earlier than 2007 (2009 for nonroad diesel)). Otherwise, the cassette and filter shall be placed in a closed Petri dish until it can be returned to the filter stabilization environment. Once the closed Petri dish is returned to the filter stabilization environment, the Petri dish shall be opened, the upper half of the cassette shall be removed using a properly designed separator tool, the lower half of the cassette-with filter-shall be placed in a partially covered Petri dish, and allowed to stabilize for at least 30 minutes (60 minutes for engines of model year earlier than 2007 (2009 for nonroad diesel)).

(6) After at least 30 minutes (60 minutes for engines of model year earlier than 2007 (2009 for nonroad diesel)), but no more than 60 hours of stabilization, each filter may be weighed using the specified microbalance. The process of weighing a filter may be repeated and a statistical mean may be calculated. Sound engineering judgment shall dictate the use of statistics to discard outliers and the weighting of averages. For a used filter, its single weight or statistical mean weight shall be identified as the uncorrected gross weight of the filter. The uncorrected gross weight shall be corrected for filter buoyancy using the procedure in (c) (3) of this section. The uncorrected gross filter weight, corrected gross filter weight, barometric pressure, temperature, and dewpoint shall be recorded.

(7) The net particulate matter weight (Pf) of each filter shall be equal to the corrected gross filter weight minus the corrected tare filter weight.

(8) Should the particulate matter on the filters contact the Petri dish, tweezers, microbalance or any other surface, the data with respect to that filter is void.

## **Subpart G—Data Analysis and Calculations**

### **§ 1065.601 Overview.**

This subpart describes how to use the responses on the analyzers and other meters to calculate final gram per kilowatt-hour emission rates.

**Note:** Volume and density values used in these calculations are generally corrected to standard conditions of 20°C and 101.3 kPa.)

### **§ 1065.605 Required records.**

Retain the following information for each test:

- (a) Test number.
- (b) System or device tested (brief description).
- (c) Date and time of day for each part of the test schedule.
- (d) Test results.
- (e) Operator's name.
- (f) Engine: ID number, manufacturer, model year, emission standards, engine family, basic engine description, fuel system, engine code, and idle speed, as applicable.
- (g) Dynamometer: Dynamometer identification, records to verify compliance with the duty cycle requirements of the test.
- (h) Gas analyzers: Analyzer bench identification, analyzer ranges, recordings of analyzer output during zero, span, and sample readings.
- (i) Recorder charts: Test number, date, identification, operator's name, and identification of the measurements recorded.
- (j) Test cell barometric pressure, ambient temperature, and humidity as required. (Some test systems may require continuous measurements; others may require a single measurement, or measurements before and after the test.)

(k) Temperatures: Records to verify compliance with the ambient temperature requirements throughout the test procedure.

(l) CFV-CVS: Total dilute exhaust volume ( $V_{mix}$ ) for each phase of the exhaust test.

(m) PDP-CVS: Test measurements for calculating the total dilute exhaust volume ( $V_{mix}$ ), and the  $V_{mix}$  for each phase of the exhaust test.

(n) The humidity of the dilution air.

**Note:** If you do not use conditioning columns, this measurement is not necessary. If you use conditioning columns and take the dilution air from the test cell, you may use the ambient humidity for this measurement.

#### **§ 1065.610 Bag sample analysis.**

(a) Zero the analyzers and obtain a stable zero reading. Recheck after tests.

(b) Introduce span gases and set instrument gains. To avoid errors, span and calibrate at the same flow rates used to analyze the test sample. Span gases should have concentrations equal to 75 to 100 percent of full scale. If gain has shifted significantly on the analyzers, check the calibrations. Show actual concentrations on the chart.

(c) Check zeroes; if necessary, repeat the procedure in paragraphs (a) and (b) of this section.

(d) Check flow rates and pressures.

(e) Measure HC, CO, CO<sub>2</sub>, and NOX concentrations of samples.

(f) Check zero and span points. If the difference is greater than 2 percent of full scale, repeat the procedure in paragraphs (a) through (e) of this section.

#### Emission measurement accuracy

##### (a) Measurement accuracy—Bag sampling.

(1) Good engineering practice dictates that exhaust emission sample analyzer readings below 15 percent of full scale chart deflection should generally not be used.

(2) Some high resolution read-out systems such as computers, data loggers, etc., can provide sufficient accuracy and resolution below 15 percent of full scale. Such systems may be used provided that additional calibrations of at least 4 non-zero nominally equally spaced points, using good engineering judgment, below 15 percent of full scale are made to ensure the accuracy of the calibration curves.

(3) The following procedure shall be followed:

(i) Span the analyzer using a calibration gas that meets the accuracy requirements, is within the operating range of the analyzer and at least 90% of full scale.

(ii) Generate calibration data over the full concentration range at a minimum of 6, approximately equally spaced, points (e.g. 15, 30, 45, 60, 75 and 90 percent of the range of concentrations provided by the gas divider). If a gas divider or blender is being used to calibrate the analyzer and the requirements of paragraph (a)(2) of this section are met, verify that a second calibration gas with a concentration between 10 and 20 percent of full scale can be named within 2 percent of its certified concentration. If more calibration points are needed to meet the requirements of paragraph (a)(2) of this section, continue with paragraph (a)(3)(iii) of this section.

(iii) If a gas divider or blender is being used to calibrate the analyzer, input the value of a second calibration gas (a span gas may be used for calibrating a CO<sub>2</sub> analyzer) having a named concentration between 10 and 20 percent of full scale. This gas shall be included on the calibration curve. Continue adding calibration points by dividing this gas until the requirements of paragraph (a)(2) of this section are met.

(iv) Fit a calibration curve for the full scale range of the analyzer using the calibration data obtained with both calibration gases.

#### Exhaust sample analysis.

(a) The analyzer response may be read by automatic data collection (ADC) equipment such as computers, data loggers, etc. If ADC equipment is used the following is required:

(1) For bag analysis, the analyzer response must be stable at greater than 99 percent of the final reading for the dilute exhaust sample bag. A single value representing the average chart deflection over a 10-second stabilized period shall be stored. For the background bag, all readings taken during the 10-second interval must be stable at the final value to within  $\pm 1$  percent of full scale.

(3) The chart deflections or average integrated concentrations required in paragraphs (a) (1) and (2) of this section may be stored on long-term computer storage devices such as computer tapes, storage discs, punch cards, or they may be printed in a listing for storage. In either case a chart recorder is not required and records from a chart recorder, if they exist, need not be stored.

(4) If the data from ADC equipment is used as permanent records, the ADC equipment and the analyzer values as interpreted by the ADC equipment are subject to the calibration specifications in §§ 86.1316 through 86.1326, as if the ADC equipment were part of the analyzer. (b) Data records from any one or a combination of analyzers may be stored as chart recorder records.

(c) Software zero and span.

(1) The use of “software” zero and span is permitted. The process of software zero and span refers to the technique of initially adjusting the analyzer zero and span responses to the calibration curve values, but for subsequent zero and span checks the analyzer response is simply recorded without adjusting the analyzer gain. The observed analyzer response recorded from the subsequent check is mathematically corrected back to the calibration curve values for zero and span. The same mathematical correction is then applied to the analyzer’s response to a sample of exhaust gas in order to compute the true sample concentration.

(2) The maximum amount of software zero and span mathematical correction is  $\pm 10$  percent of full scale chart deflection.

(3) Software zero and span may be used to switch between ranges without adjusting the gain of the analyzer.

(4) The software zero and span technique may not be used to mask analyzer drift. The observed chart deflection before and after a given time period or event shall be used for computing the drift. Software zero and span may be used after the drift has been computed to mathematically adjust any span drift so that the “after” span check may be transformed into the “before” span check for the next segment.

(d) For bag sample analysis perform the following sequence:

(1) Warm-up and stabilize the analyzers; clean and/or replace filter elements, conditioning columns (if used), etc., as necessary. (2) Obtain a stable zero reading.

(3) Zero and span the analyzers with zero and span gases. The span gases shall have concentrations between 75 and 100 percent of full-scale chart deflection. The flow rates and system pressures during spanning shall be approximately the same as those encountered during sampling. A sample bag may be used to identify the required analyzer range.

(4) Re-check zero response. If this zero response differs from the zero response recorded in paragraph (d)(3) of this section by more than 1 percent of full scale, then paragraphs (d) (2), (3), and (4) of this section should be repeated.

(5) If a chart recorder is used, identify and record the most recent zero and span response as the pre-analysis values.

(6) If ADC equipment is used, electronically record the most recent zero and span response as the pre-analysis values.

(d)(7) Measure HC (except diesels), CH<sub>4</sub> (natural gas-fueled engines only), CO, CO<sub>2</sub>, and NO<sub>x</sub> sample bag(s) with approximately the same flow rates and pressures. (Constituents measured continuously do not require bag analysis.)

(8) A post-analysis zero and span check of each range must be performed and the values recorded. The number of events that may occur between the pre and post checks is not specified. However, the difference between pre-analysis zero and span values (recorded in paragraph (d) (5) or (6) of this section) versus those recorded for the post-analysis check may not exceed the zero drift limit or the span drift limit of 2 percent of full scale chart deflection for any range used. Otherwise the test is void.

(e) For continuous sample analysis perform the following sequence:

(1) Warm-up and stabilize the analyzers; clean and/or replace filter elements, conditioning columns (if used), etc., as necessary.

(2) Leak check portions of the sampling system that operate at negative gauge pressures when sampling, and allow heated sample lines, filters, pumps, etc., to stabilize at operating temperature.

(3) Optional: Perform a hang-up check for the HFID sampling system:

(i) Zero the analyzer using zero air introduced at the analyzer port.

(ii) Flow zero air through the overflow sampling system. Check the analyzer response.

(iii) If the overflow zero response exceeds the analyzer zero response by 2 percent or more of the HFID full-scale deflection, hang-up is indicated and corrective action must be taken.

(iv) The complete system hang-up check specified in paragraph (f) of this section is recommended as a periodic check.

(4) Obtain a stable zero reading.

(5) Zero and span each range to be used on each analyzer used prior to the beginning of the cold cycle. The span gases shall have a concentration between 75 and 100 percent of full scale chart deflection. The flow rates and system pressures shall be approximately the same as those encountered during sampling. The HFID analyzer shall be zeroed and spanned through the overflow sampling system.

(6) Re-check zero response. If this zero response differs from the zero response recorded in paragraph (e)(5) of this section by more than 1 percent of full scale, then paragraphs (e) (4), (5), and (6) of this section should be repeated.

(7) If a chart recorder is used, identify and record the most recent zero and span response as the pre-analysis values.

(8) If ADC equipment is used, electronically record the most recent zero and span response as the pre-analysis values.

(9) Measure the emissions (HC required for diesels; NOX, CO, CO2 optional) continuously during the cold start cycle. Indicate the start of the test, the range(s) used, and the end of the test on the recording medium (chart paper or ADC equipment). Maintain approximately the same flow rates and system pressures used in paragraph (e)(5) of this section.

(10) Collect background HC, CO, CO2, and NOX in a sample bag.

(11) Perform a post-analysis zero and span check for each range used at the conditions specified in paragraph (e)(5) of this section. Record these responses as the post-analysis values.

(12) Neither the zero drift nor the span drift between the pre-analysis and post-analysis checks on any range used may exceed 3 percent for HC, or 2 percent for NOX, CO, and CO2, of full scale chart deflection, or the test is void. (If the HC drift is greater than 3 percent of full-scale chart deflection, hydrocarbon hang-up is likely.)

(13) Determine HC background levels for the cold start cycle by introducing the background sample into the overflow sample system.

(14) Determine background levels of NOX, CO, or CO2 (if necessary) by the bag technique outlined in paragraph (d) of this section.

(15) Repeat paragraphs (e) (4) through (14) of this section for the hot cycle. The post-analysis zero and span check for the cold start (or previous hot start) cycle may be used for the pre-analysis zero and span for the following hot start cycle.

(f) HC hang-up. If HC hang-up is indicated, the following sequence may be performed:

(1) Fill a clean sample bag with background air.

(2) Zero and span the HFID at the analyzer ports.

(3) Analyze the background air sample bag through the analyzer ports.

(4) Analyze the background air through the entire sample probe system.

(5) If the difference between the readings obtained is 2 percent or more of the HFID full scale deflection, clean the sample probe and the sample line.

(6) Reassemble the sample system, heat to specified temperature, and repeat the procedure in paragraphs (f) (1) through (6) of this section.

#### **§ 1065.615 Bag sample calculations.**

(a) General requirements. Calculate all volumes and volumetric flow rates at standard conditions for temperature and pressure (0 °C and 101.3 kPa), and these conditions must be used consistently throughout all calculations.

(a) Calculate the dilution factor. The dilution factor is the ratio of the total volume of the raw exhaust to the total volume of the diluted exhaust. It is calculated as 134,000 divided by the sum of the diluted ppmC concentrations of carbon-containing compounds in the exhaust, as follows:

$$DF = 134,000 / (CO_{2sample} + THC_{sample} + CO_{sample}),$$

Where:

CO<sub>2sample</sub> and CO<sub>sample</sub> are expressed as ppm, and THC<sub>sample</sub> is expressed as ppmC.

(b) Calculate mass emission rates (g/test) for the transient segment using the general equation in paragraph (b)(1) of this section:

(1) The general equation is: Emission rate = (total dilute exhaust flow volume)(ppm)(density factor)/10<sup>6</sup>

$$M_x = (V_{mix})(C_i)(fd_i)/10^6$$

Where:

M<sub>x</sub> = Mass emission rate in g/test segment.

V<sub>mix</sub> = Total dilute exhaust flow volume flow in m<sup>3</sup> per test segment corrected to 20°C and 101.3 kPa.

C<sub>i</sub> = The concentration of species i, in ppm or ppmC, corrected for background contribution according to the equation in paragraph (b)(2) of this section.

$f_{di}$  = The density factor for species  $i$ . The density factors are 576.8 g/m<sup>3</sup> for THC, 1913 g/m<sup>3</sup> for NOX, and 1164 g/m<sup>3</sup> for CO.

(2) The equation to calculate  $C_i$  is:

$$C_i = C_{\text{sample}} - C_{\text{background}} [1 - (1/DF)]$$

Where:

$C_{\text{sample}}$  = Concentration of species  $i$  in the diluted exhaust sample, in ppm or ppmC.

$C_{\text{background}}$  = Concentration of species  $i$  in the dilution air background sample, in ppm or ppmC.

DF = Dilution factor, as calculated in paragraph (a) of this section.

(c) Calculate total brake work (kW-hr) done during the emissions sampling period of each segment or mode.

(d) Calculate emissions in g/kW-hr by dividing the mass emission rate (g/test segment) by the total brake work for the test segment.

(e) Apply deterioration factors or other adjustment factors to the brake specific emission rate in paragraph (e) as specified in the standard-setting part.

# § 86.344-79 Humidity calculations.

(a) The following abbreviations (and units) are used in this section:

BARO = barometric pressure (Pa)  
*H* = specific humidity, (gm H<sub>2</sub>O/gm of dry air)  
*K* = 0.6220 gm H<sub>2</sub>O/gm dry air  
*M*<sub>air</sub> = Molecular weight of air = 28.9645  
*M*<sub>H<sub>2</sub>O</sub> = Molecular weight of water = 18.01534  
*P*<sub>DB</sub> = Saturation vapor pressure of water at the dry bulb temperature (Pa)  
*P*<sub>DP</sub> = saturation vapor pressure of water at the dewpoint temperature (Pa)  
*P*<sub>v</sub> = partial pressure of water vapor (Pa)  
*P*<sub>WB</sub> = saturation vapor pressure of water at the wet bulb temperature (pa)  
*T*<sub>DB</sub> = Dry bulb temperature (°K)  
*T*<sub>WB</sub> = Wet bulb temperature (°K)  
*Y* = Water-vapor volume concentration

(b) The specific humidity on a dry basis of the intake air (*H*) is defined by equation (1).

$$H = \frac{(K)(P_v)}{BARO - P_v} \quad (1)$$

(c) The partial pressure of water vapor may be determined in two manners:

(1) A dew point device may be used. In that case:

$$P_v = P_{DP}$$

(2) A wet-bulb, dry-bulb method may be used. In that case "Ferrels equation" (eq. (2)) is used.

$$P_v = P_{WB} - 0.000660(T_{DB} - T_{WB})BARO[1 + 0.00115(T_{WB} - 273.15)] \quad (2)$$

(d)(1) The saturation vapor pressure (*P*<sub>WB</sub>) of water at the wet-bulb temperature is defined by equation (3) (Ref. Wexler and Greenspan, equation (23), National Bureau of Standards).

$$P_{WB} = \exp \left[ B \ln T_{WB} + \sum_{i=0}^9 F_i T_{WB}^{i-2} \right] \quad (3)$$

where:

*P*<sub>WB</sub> is in Pascals (Pa)  
*T*<sub>WB</sub> = Web-bulb temperature (°K)  
*B* = - 12.150799  
*F*<sub>0</sub> = - 8.49922(10)<sup>3</sup>  
*F*<sub>1</sub> = - 7.4231865(10)<sup>3</sup>  
*F*<sub>2</sub> = 96.1635147  
*F*<sub>3</sub> = 2.4917646(10) - 2  
*F*<sub>4</sub> = - 1.3160119(10) - 5  
*F*<sub>5</sub> = - 1.1460454(10) - 8  
*F*<sub>6</sub> = 2.1701289(10) - 11  
*F*<sub>7</sub> = - 3.610258(10) - 15  
*F*<sub>8</sub> = 3.8504519(10) - 18  
*F*<sub>9</sub> = - 1.4317(10) - 21

(2) The table in Figure D79-5 may be used in lieu of equation (3).

(e) The saturated vapor pressure of water at the dry-bulb temperature (*P*<sub>DB</sub>) is found (if required) by using dry-bulb absolute temperature (°K) in equation (3).

(f) The percent of relative humidity (*RH*) (if required) is defined by equation (4).

$$RH = \frac{P_n}{P_{DB}}(100) \quad (4)$$

(g) The water-vapor volume concentration on a dry basis of the engine intake air (*Y*) is defined by equation (5).

$$Y = \frac{(H)(M_{air})}{(M_{H_2O})} - \frac{P_v}{BARO - P_v} \quad (5)$$

FIGURE D79-5—SATURATION VAPOR PRESSURE OVER WATER (PASCALS)

Temperature °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0 .....	610.752	615.207	619.690	624.203	628.744	633.315	637.916	642.545	647.205	651.894
1 .....	656.614	661.364	666.144	670.955	675.796	680.669	685.572	690.507	695.473	700.471
2 .....	705.500	710.562	715.655	720.781	725.939	731.130	736.354	741.611	746.901	752.224
3 .....	757.581	762.971	768.396	773.854	779.347	784.874	790.436	796.033	801.664	807.331
4 .....	813.034	818.771	824.545	830.355	836.200	842.082	848.001	853.956	859.948	865.978
5 .....	872.045	878.149	884.291	890.470	896.688	902.945	909.239	915.573	921.945	928.357
6 .....	934.808	941.298	947.828	954.399	961.009	967.660	974.351	981.083	987.856	994.670
7 .....	1001.53	1008.42	1015.36	1022.34	1029.37	1036.43	1043.54	1050.70	1057.89	1065.13
8 .....	1072.41	1079.74	1087.11	1094.52	1101.98	1109.48	1117.03	1124.63	1132.27	1139.95
9 .....	1147.68	1155.46	1163.28	1171.15	1179.07	1187.04	1195.05	1203.11	1211.21	1219.37
10 .....	1227.57	1235.83	1244.13	1252.48	1260.88	1269.32	1277.82	1286.37	1294.97	1303.62
11 .....	1312.32	1321.07	1329.87	1338.73	1347.63	1356.59	1365.60	1374.67	1383.78	1392.95

FIGURE D79-5—SATURATION VAPOR PRESSURE OVER WATER (PASCALS)—Continued

Temperature °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
12 .....	1402.17	1411.45	1420.78	1430.16	1439.60	1449.10	1458.64	1468.25	1477.91	1487.62
13 .....	1497.39	1507.22	1517.11	1527.05	1537.04	1547.10	1557.21	1567.39	1577.62	1587.90
14 .....	1598.25	1608.66	1619.12	1629.65	1640.24	1650.88	1661.59	1672.36	1683.18	1694.08
15 .....	1705.03	1716.04	1727.12	1738.26	1749.46	1760.73	1772.06	1783.45	1794.91	1806.43
16 .....	1818.01	1829.67	1841.38	1853.17	1865.02	1876.93	1888.91	1900.96	1913.08	1925.27
17 .....	1937.52	1949.84	1962.23	1974.69	1987.21	1999.81	2012.48	2025.21	2038.02	2050.90
18 .....	2063.85	2076.87	2089.97	2103.13	2116.37	2129.68	2143.07	2156.53	2170.06	2183.66
19 .....	2197.34	2211.10	2224.93	2238.84	2252.82	2266.88	2281.02	2295.23	2309.52	2323.89
20 .....	2338.34	2352.86	2367.47	2382.15	2396.91	2411.76	2426.68	2441.68	2456.77	2471.93
21 .....	2487.18	2502.51	2517.93	2533.42	2549.00	2564.66	2580.41	2596.24	2612.16	2628.16
22 .....	2644.25	2660.42	2676.68	2693.02	2709.46	2725.98	2742.59	2759.28	2776.07	2792.94
23 .....	2809.91	2826.96	2844.11	2861.34	2878.67	2896.09	2913.60	2931.20	2948.89	2966.68
24 .....	2984.56	3002.54	3020.61	3038.77	3057.03	3075.39	3093.84	3112.39	3131.03	3149.78
25 .....	3168.62	3187.55	3206.59	3225.73	3244.96	3264.30	3283.73	3303.27	3322.91	3342.65
26 .....	3362.49	3382.43	3402.48	3422.63	3442.89	3463.24	3483.71	3504.28	3524.95	3545.73
27 .....	3566.62	3587.62	3608.72	3629.93	3651.25	3672.67	3694.21	3715.86	3737.61	3759.48
28 .....	3781.46	3803.55	3825.75	3848.07	3870.50	3893.04	3915.70	3938.47	3961.36	3984.36
29 .....	4007.48	4030.71	4054.06	4077.53	4101.12	4124.83	4148.65	4172.59	4196.66	4220.84
30 .....	4245.15	4269.58	4294.13	4318.80	4343.60	4368.52	4393.56	4418.73	4444.02	4469.44

**§ 1065.620 Continuous sampling calculations.**

**(b) Measurement accuracy—Continuous sampling.**

**(1) Analyzers used for continuous analysis must be operated such that the measured concentration falls between 15 and 100 percent of full scale chart deflection. Exceptions to these limits are:**

**(i) Analyzer response less than 15 percent or more than 100 percent of full scale may be used if automatic range change circuitry is used and the limits for range changes are between 15 and 100 percent of full scale chart deflection;**

**(ii) Analyzer response less than 15 percent of full scale may be used if one of the following is true:**

**(A) Alternative (a)(2) of this section is used to ensure that the accuracy of the calibration curve is maintained below 15 percent; or**

**(B) The full scale value of the range is 155 ppm (C) or less.**

**(iii) Analyzer response over 100% of full scale may be used if it can be shown that readings in this range are accurate.**

**(c) If a gas divider is used, the gas divider shall conform to the accuracy requirements specified in § 86.1314–84(g), and shall be used according to the procedures contained in (a) and (b) of this section**

**(a) General requirements. Calculate all volumes and volumetric flow rates at standard conditions for temperature and pressure (0 °C and 101.3 kPa), and these conditions must be used consistently throughout all calculations.**

**(2) For continuous analysis systems, the ADC system must read at least two analyzer readings per second. A single value representing the average integrated concentration over a cycle shall be stored.**

**(3) The chart deflections or average integrated concentrations required in paragraphs (a) (1) and (2) of this section may be stored on long-term computer storage devices such as computer tapes, storage discs, punch cards, or they may be printed in a listing for storage. In either case a chart recorder is not required and records from a chart recorder, if they exist, need not be stored.**

**(4) If the data from ADC equipment is used as permanent records, the ADC equipment and the analyzer values as interpreted by the ADC equipment are subject to the calibration specifications as if the ADC equipment were part of the analyzer. (b) Data records from any one or a combination of analyzers may be stored as chart recorder records.**

**(c) Software zero and span.**

**(1) The use of “software” zero and span is permitted. The process of software zero and span refers to the technique of initially adjusting the analyzer zero and span responses to the calibration curve values, but for subsequent zero and span checks the analyzer response is simply recorded without adjusting the analyzer gain. The observed analyzer response recorded from the subsequent check is mathematically corrected back to the calibration curve values for zero and span. The same mathematical correction is then applied to the analyzer’s response to a sample of exhaust gas in order to compute the true sample concentration.**

(2) The maximum amount of software zero and span mathematical correction is  $\pm 10$  percent of full scale chart deflection.

(3) Software zero and span may be used to switch between ranges without adjusting the gain of the analyzer.

(4) The software zero and span technique may not be used to mask analyzer drift. The observed chart deflection before and after a given time period or event shall be used for computing the drift. Software zero and span may be used after the drift has been computed to mathematically adjust any span drift so that the “after” span check may be transformed into the “before” span check for the next segment.

(e) For continuous sample analysis perform the following sequence:

(1) Warm-up and stabilize the analyzers; clean and/or replace filter elements, conditioning columns (if used), etc., as necessary.

(2) Leak check portions of the sampling system that operate at negative gauge pressures when sampling, and allow heated sample lines, filters, pumps, etc., to stabilize at operating temperature.

(3) Optional: Perform a hang-up check for the HFID sampling system:

(i) Zero the analyzer using zero air introduced at the analyzer port.

(ii) Flow zero air through the overflow sampling system. Check the analyzer response.

(iii) If the overflow zero response exceeds the analyzer zero response by 2 percent or more of the HFID full-scale deflection, hang-up is indicated and corrective action must be taken.

(iv) The complete system hang-up check specified in paragraph (f) of this section is recommended as a periodic check.

(4) Obtain a stable zero reading.

(5) Zero and span each range to be used on each analyzer used prior to the beginning of the cold cycle. The span gases shall have a concentration between 75 and 100 percent of full scale chart deflection. The flow rates and system pressures shall be approximately the same as those encountered during sampling. The HFID analyzer shall be zeroed and spanned through the overflow sampling system.

(6) Re-check zero response. If this zero response differs from the zero response recorded in paragraph (e)(5) of this section by more than 1 percent of full scale, then paragraphs (e) (4), (5), and (6) of this section should be repeated.

(7) If a chart recorder is used, identify and record the most recent zero and span response as the pre-analysis values.

(8) If ADC equipment is used, electronically record the most recent zero and span response as the pre-analysis values.

(9) Measure the emissions (HC required for diesels; NOX, CO, CO2 optional) continuously during the cold start cycle. Indicate the start of the test, the range(s) used, and the end of the test on the recording medium (chart paper or ADC equipment). Maintain approximately the same flow rates and system pressures used in paragraph (e)(5) of this section.

(10) Collect background HC, CO, CO2, and NOX in a sample bag.

(11) Perform a post-analysis zero and span check for each range used at the conditions specified in paragraph (e)(5) of this section. Record these responses as the post-analysis values.

(12) Neither the zero drift nor the span drift between the pre-analysis and post-analysis checks on any range used may exceed 3 percent for HC, or 2 percent for NOX, CO, and CO2, of full scale chart deflection, or the test is void. (If the HC drift is greater than 3 percent of full-scale chart deflection, hydrocarbon hang-up is likely.)

(13) Determine HC background levels for the cold start cycle by introducing the background sample into the overflow sample system.

(14) Determine background levels of NOX, CO, or CO2 (if necessary) by the bag technique outlined in paragraph (d) of this section.

(15) Repeat paragraphs (e) (4) through

(14) of this section for the hot cycle. The post-analysis zero and span check for the cold start (or previous hot start) cycle may be used for the pre-analysis zero and span for the following hot start cycle.

For the evaluation of the gaseous emission recording, the last 60 seconds of each mode are recorded, and the average values for HC, CO, CO2, and NOX during each mode are determined from the average concentration readings determined from the corresponding calibration data.

Raw exhaust gas flow.

The exhaust gas flow shall be determined by one of the methods described in this section and conform to the tolerances of Table 3 in appendix A to subpart D:

(a) Measurement of the air flow and the fuel flow by suitable metering systems (for details see SAE J244. This procedure has been incorporated by reference.

See § 89.6.) and calculation of the exhaust gas flow as follows:

$G_{EXHW} = G_{AIRW} + G_{FUEL}$  (for wet exhaust mass)

or

$V_{EXHD} = V_{AIRD} + (¥.767) \times G_{FUEL}$  (for dry exhaust volume)

or

$V_{EXHW} = V_{AIRW} + .749 \times G_{FUEL}$  (for wet exhaust volume)

(b) Exhaust mass calculation from fuel consumption (see § 89.415) and exhaust gas concentrations using the method found in § 89.418.

Raw emission sampling calculations.

(a) The final test results shall be derived through the steps described in this section.

(b) The exhaust gas flow rate  $G_{EXHW}$  and  $V_{EXHW}$  shall be determined for each mode.

(1) For measurements using the mass flow method, see § 89.416(a).

(2) For measurements using the fuel consumption and exhaust gas concentrations method, use the following equations:

$$G_{EXHW} = G_{fuel} + G_{aird} \left( 1 + \left( \frac{H}{1000} \right) \right)$$

Where:

$$G_{aird} = \frac{G_{fuel}}{(fla)} = \frac{\text{Mass Fuel Measured}}{G_{airw} \times \left( 1 - \frac{H}{1000} \right)}$$

$$(fla) = \frac{4.77 (1 + \alpha/4) (fla)_{stoich}}{\frac{1}{X} - \left( \frac{DCO}{2X(10)^6} \right) - \left( \frac{DHC}{X(10)^6} \right) + \frac{\alpha}{4} \left( 1 - \frac{DHC}{X(10)^6} \right) - \frac{0.75 \alpha}{\left( \frac{K}{\left( \frac{DCO}{X(10)^6} \right)} \right) + \left( \frac{(1-K)}{\left( 1 - \frac{DHC}{X(10)^6} \right)} \right)}$$

$$(fla)_{stoich} = \frac{M_c + \alpha M_H}{138.18 (1 + \alpha/4)}$$

$$X = \frac{DCO_2}{10^2} + \frac{DCO}{10^6} + \frac{DHC}{10^6}$$

K = 3.5 (3) Humidity values may be calculated from either one of the following equations:

$$H = \frac{6.22 \times R_a \times p_d}{p_R - (p_d \times R_a \times 10^{-2})}$$

or

$$H = \frac{622 \times P_v}{(P_B - P_v)}$$

(c) When applying GEXHW, the measured “dry” concentration shall be corrected to a wet basis, if not already measured on a wet basis. This section is applicable only for measurements made on raw exhaust gas. Correction to a wet basis shall be according to the following formula:

$$\text{ConcWET} = K_w \times \text{ConcDRY}$$

Where:

KW is determined according to the equations in paragraph (c)(1) or (c)(2) of this section.

(1) For measurements using the mass flow method (see § 89.416(a)):

$$K_w = \left[ 1 - F_{FH} \times \frac{G_{\text{fuel}}}{G_{\text{aird}}} \right] - K_{w1}$$

$$F_{FH} = ALF \times 0.1448 \times \frac{1}{1 + \left( \frac{G_{\text{fuel}}}{G_{\text{aird}}} \right)} \text{ for diesel fuel only}$$

$$ALF = \text{Hydrogen mass percentage of fuel} = \frac{1.008 \times \alpha}{12.01 + 1.008 \times \alpha} \times 100 = 13.12 \text{ for } CH_{1.8} \text{ fuel}$$

a = H/C mole ratio of the fuel.

(2) For measurements using the fuel consumption and exhaust gas concentrations method (see § 89.416(b)):

$$K_w = \frac{1}{1 + 1.8 \times 0.005 \times \left[ \frac{DCO}{10^4} = DCO_2 \right]} - K_{w1}$$

Where,

$$K_{w1} = \frac{1.608 \times H}{1000 + 1.608 \times H}$$

(d) As the NOX emission depends on intake air conditions, the NOX concentration shall be corrected for intake air temperature and humidity with the factor Kh given in the following formula.

For engines operating on alternative combustion cycles, other correction formulas may be used if they can be justified or validated. The formula follows:

$$K_H = \frac{1}{1 - 0.0182(H - 10.71)}$$

(e) The pollutant mass flow for each mode shall be calculated as follows:

$$\text{Gas mass} = u \times \text{Gas conc.} \times \text{GEXHW}$$

$$\text{Gas mass} = v \times \text{Gas conc.} \times \text{VEXHD}$$

$$\text{Gas mass} = w \times \text{Gas conc.} \times \text{VEXHW}$$

The coefficients u (wet), v (dry), and w (wet) are to be used according to the following table:

Gas	u	v	w	conc.
NO <sub>x</sub> .....	0.001587	0.00205	0.00205	ppm.
CO .....	0.000966	0.00125	0.00125	ppm.
HC .....	0.000478		0.000618	ppm.
CO <sub>2</sub> .....	15.19	19.64	19.64	percent.

**NOTE:**

The given coefficients u, v, and w are calculated for 273.15 °K (0 °C) and 101.3 kPa. In cases where the reference conditions vary from those stated, an error may occur in the calculations.

(f) The following equations may be used to calculate the coefficients u, v, and w in paragraph (e) of this section for other conditions of temperature and pressure:

(1) For the calculation of u, v, and w for NO<sub>x</sub> (as NO<sub>2</sub>), CO, HC (in paragraph (e) of this section as CH<sub>1.80</sub>), CO<sub>2</sub>, and O<sub>2</sub>:

Where:

$w = 4.4615.105 \times M$  if conc. in ppm

$w = 4.4615.101 \times M$  if conc. in percent

$v = \frac{w}{r_{Air}}$

$u = \frac{w}{r_{Air}}$

M = Molecular weight

r<sub>Air</sub> = Density of dry air at 273.15 °K (0 °C),

101.3 kPa = 1.293 kg/m<sup>3</sup>

(2) For real gases at 273.15 °K (0 °C)

and 101.3 kPa: For the calculation of u,

v, and w

$w = \text{gas} \times 10^{-6}$  if conc. in ppm

$v = \frac{w}{p_{Gas}}$

$u = \frac{w}{p_{Gas}}$

p<sub>Gas</sub> = Density of measured gas at 0 °C, 101.3

kPa in g/m<sup>3</sup>

(3) General formulas for the calculation of concentrations at temperature (designated as T) and pressure (designated as p):

--for ideal gases

$$\text{conc} \frac{\text{g}}{\text{m}_3} = \frac{M}{M_v} \times \frac{T_0}{T_0 + T} \times \frac{P}{P_0} \frac{\text{Conc(ppm)}}{10^6}$$

--For real gases

$$\text{conc} \frac{\text{g}}{\text{m}_3} = \rho_{\text{Gas}} \times \frac{T_0}{T_0 + T} \times \frac{P}{P_0} \frac{\text{Conc(ppm)}}{10^6}$$

with:

1% = 104 ppm

M = Molecular weight in g/Mol

M<sub>v</sub> = Molecular Volume = 22.414 × 10<sup>-3</sup> m<sup>3</sup>/

Mol for ideal gases

T = reference temperature 273.15 K

p = reference pressure 101.3 kPa

T = Temperature in °C

p = pressure in kPa

p<sub>Gas</sub> = Density of the measured gas at 0 °C,

101.3 kPa

Conc. = Gas concentration

(g)(1) The emission shall be calculated for all individual components in the following way where power at idle is equal to zero:

$$\text{individual gas} = \frac{\sum_{i=1}^{i=n} (g_i \times WF_i)}{\sum_{i=1}^{i=n} (P_i \times WF_i)}$$

(2) The weighting factors and the number of modes (n) used in the calculation in paragraph (g)(1) of this section are according to § 89.410.

## **Subpart H—Particulate Measurements [Reserved]**

## **Subpart I—Testing With Oxygenated Fuels**

### **§ 1065.801 Applicability.**

(a) This subpart applies for testing with oxygenated fuels. Except where specified otherwise in the standard setting part, compliance with this subpart is not required for fuels that contain less than 25 percent oxygenated compounds by volume. For example, you generally would not need to follow the requirements of this subpart for tests performed using a fuel that was 10 percent ethanol and 90 percent gasoline, but you would need to follow these requirements for tests performed using a fuel that was 85 percent ethanol and 15 percent gasoline.

(b) This subpart specifies sampling procedures and calculations that are different than those used for nonoxygenated fuels. The other test procedures of this part apply for testing with oxygenated fuels.

### **§ 1065.805 Sampling system.**

(a) Use the sampling procedures specified in 40 CFR part 86 for methanol and formaldehyde to measure alcohols and aldehydes in the exhaust. This requires the following:

- (1) Bubbling a sample of the exhaust through water to collect the alcohols.
- (2) Passing a sample of the exhaust through cartridges impregnated with 2,4-dinitrophenylhydrazine to measure aldehydes.

(b) Use good engineering judgment to measure other oxygenated compounds in the exhaust.

### **§ 1065.810 Calculations.**

(a) *THCE emissions.* (1) Calculate THCE emissions as the sum of the mass of the nonoxygenated hydrocarbons in the exhaust and the carbon-equivalent mass of each measured oxygenated species in the exhaust.

(2) Calculate carbon-equivalent mass of each measured oxygenated species from the following equation:

$$\text{Carbon equivalent} = 13.8756 \times \text{MOC}/\text{MWPC}$$

Where:

MOC is the mass of the oxygenated compound in the exhaust, and MWPC is the molecular weight of compound per carbon atom of compound.

(b) *NMHCE emissions.* Calculate NMHCE emissions as either:

- (1) The sum of the mass of the nonoxygenated nonmethane hydrocarbons in the exhaust and the carbon-equivalent mass of each measured oxygenated species in the exhaust.
- (2) THCE minus the mass of methane in the exhaust.

(c) *Sample calculation.* (1) Assume the following emissions for a test: 40.00 grams of nonoxygenated hydrocarbons, 100.00 grams of ethanol, and 10.00 grams of acetaldehyde, and 1.00 gram of formaldehyde.

(2) The carbon-equivalent of the masses of oxygenated compounds are:

- (i)  $13.8756 \times 100.00 / (46.068/2) = 60.24$  grams of ethanol.
  - (ii)  $13.8756 \times 10.00 / (44.052/2) = 6.30$  grams of acetaldehyde.
  - (iii)  $13.8756 \times 1.00 / (30.026) = 0.46$  grams of formaldehyde.
- (3) THCE = 40.00 + 60.24 + 6.30 + 0.46 = 107.00 grams per test.

## **Subpart J—Field Testing**

### § 1065.901 Applicability.

- (a) The test procedures in this subpart measure brake-specific emissions from engines while they remain installed in vehicles or equipment in the field.
- (b) These test procedures apply to your engines as specified in the standard-setting part. For example, part 1048 of this chapter specifies emission standard to be used for in-use tests conducted in accordance with the provisions of this part. Unless this subpart is specifically mentioned in the standard-setting part, compliance with the provisions of this subpart is not required.

### § 1065.905 General provisions.

- (a) Unless the standard-setting part specifies deviations from the provisions of this subpart, testing conducted under this subpart must conform to all of the provisions of this subpart.
- (b) Testing conducted under this subpart may include any normal in-use operation of the engine.

### § 1065.910 Measurement accuracy and precision.

(a) Measurement systems used for field testing must be comparable to those used for dynamometer testing. A field testing measurement system shall have documentation indicating that it has been compared to a dynamometer system. The two systems must be calibrated independently to NIST traceable standards or equivalent national standards for this comparison. Other standards may be approved in advance by the Administrator. Calculations of emissions results for this test should be consistent with the field testing data reduction scheme for both the in-use equipment and the dynamometer equipment, and each complete test cycle will be considered one “summing interval”, Si as defined in the field-testing data reduction scheme.

While other statistical analyses may be acceptable, it is recommended that the comparison be based on a minimum of seven (7) repeats of collocated and simultaneous tests. This comparison shall be performed over the applicable steady-state and transient test cycles using an engine that is fully warmed up such that its coolant temperature is thermostatically controlled. If there is no applicable transient test cycle, the applicable steady-state cycle may be used. Anyone who intends to submit an alternative comparison is encouraged to first contact EPA Office of Transportation and Air Quality, Assessment and Standards Division to discuss the applicant’s intended statistical analysis. The Division may provide further guidance specific to the appropriate statistical analysis for the respective application. While other statistical analyses may be used, the following statistical tests are suggested. If the comparison is paired, it must demonstrate that the alternate system passes a two-sided, paired t-test. If the test is unpaired, it must demonstrate that the alternate system passes a two-sided, unpaired t-test. The average of these tests for the reference system must return results less than or equal to the applicable emissions standard. The t-test is performed as follows, where “n” equals the number of tests:

- (1) Calculate the average of the In-use system results; this is  $I_{avg}$ .
- (2) Calculate the average of the results of the system to which the in-use system was Referenced; this is  $R_{avg}$ .
- (3) Calculate the “n-1” standard deviations for the in-use and reference averages; these are  $I_{sd}$  and  $R_{sd}$  respectively.
- Form the F ratio:  $F = (I_{sd}/R_{sd})^2$ . F must be less than the critical F value,  $F_{crit}$  at a 95% confidence interval for “n-1” degrees of freedom. The following table lists 95% confidence interval  $F_{crit}$  values for n-1 degrees of freedom. Note that  $n_A$  represents the number of alternate system samples, while  $n_R$  represents the number of reference system samples.

	<u>nI- 1</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>
<u>nR- 1</u>																
<u>6</u>		<u>4.284</u>	<u>4.207</u>	<u>4.147</u>	<u>4.099</u>	<u>4.06</u>	<u>4.027</u>	<u>4</u>	<u>3.976</u>	<u>3.956</u>	<u>3.938</u>	<u>3.922</u>	<u>3.908</u>	<u>3.896</u>	<u>3.884</u>	<u>3.874</u>
<u>7</u>		<u>3.866</u>	<u>3.787</u>	<u>3.726</u>	<u>3.677</u>	<u>3.637</u>	<u>3.603</u>	<u>3.575</u>	<u>3.55</u>	<u>3.529</u>	<u>3.511</u>	<u>3.494</u>	<u>3.48</u>	<u>3.467</u>	<u>3.455</u>	<u>3.445</u>
<u>8</u>		<u>3.581</u>	<u>3.5</u>	<u>3.438</u>	<u>3.388</u>	<u>3.347</u>	<u>3.313</u>	<u>3.284</u>	<u>3.259</u>	<u>3.237</u>	<u>3.218</u>	<u>3.202</u>	<u>3.187</u>	<u>3.173</u>	<u>3.161</u>	<u>3.15</u>
<u>9</u>		<u>3.374</u>	<u>3.293</u>	<u>3.23</u>	<u>3.179</u>	<u>3.137</u>	<u>3.102</u>	<u>3.073</u>	<u>3.048</u>	<u>3.025</u>	<u>3.006</u>	<u>2.989</u>	<u>2.974</u>	<u>2.96</u>	<u>2.948</u>	<u>2.936</u>
<u>10</u>		<u>3.217</u>	<u>3.135</u>	<u>3.072</u>	<u>3.02</u>	<u>2.978</u>	<u>2.943</u>	<u>2.913</u>	<u>2.887</u>	<u>2.865</u>	<u>2.845</u>	<u>2.828</u>	<u>2.812</u>	<u>2.798</u>	<u>2.785</u>	<u>2.774</u>
<u>11</u>		<u>3.095</u>	<u>3.012</u>	<u>2.948</u>	<u>2.896</u>	<u>2.854</u>	<u>2.818</u>	<u>2.788</u>	<u>2.761</u>	<u>2.739</u>	<u>2.719</u>	<u>2.701</u>	<u>2.685</u>	<u>2.671</u>	<u>2.658</u>	<u>2.646</u>
<u>12</u>		<u>2.996</u>	<u>2.913</u>	<u>2.849</u>	<u>2.796</u>	<u>2.753</u>	<u>2.717</u>	<u>2.687</u>	<u>2.66</u>	<u>2.637</u>	<u>2.617</u>	<u>2.599</u>	<u>2.583</u>	<u>2.568</u>	<u>2.555</u>	<u>2.544</u>
<u>13</u>		<u>2.915</u>	<u>2.832</u>	<u>2.767</u>	<u>2.714</u>	<u>2.671</u>	<u>2.635</u>	<u>2.604</u>	<u>2.577</u>	<u>2.554</u>	<u>2.533</u>	<u>2.515</u>	<u>2.499</u>	<u>2.484</u>	<u>2.471</u>	<u>2.459</u>
<u>14</u>		<u>2.848</u>	<u>2.764</u>	<u>2.699</u>	<u>2.646</u>	<u>2.602</u>	<u>2.565</u>	<u>2.534</u>	<u>2.507</u>	<u>2.484</u>	<u>2.463</u>	<u>2.445</u>	<u>2.428</u>	<u>2.413</u>	<u>2.4</u>	<u>2.388</u>

15		2.79	2.707	2.641	2.588	2.544	2.507	2.475	2.448	2.424	2.403	2.385	2.368	2.353	2.34	2.328
16		2.741	2.657	2.591	2.538	2.494	2.456	2.425	2.397	2.373	2.352	2.333	2.317	2.302	2.288	2.276
17		2.699	2.614	2.548	2.494	2.45	2.413	2.381	2.353	2.329	2.308	2.289	2.272	2.257	2.243	2.23
18		2.661	2.577	2.51	2.456	2.412	2.374	2.342	2.314	2.29	2.269	2.25	2.233	2.217	2.203	2.191
19		2.628	2.544	2.477	2.423	2.378	2.34	2.308	2.28	2.256	2.234	2.215	2.198	2.182	2.168	2.155
20		2.599	2.514	2.447	2.393	2.348	2.31	2.278	2.25	2.225	2.203	2.184	2.167	2.151	2.137	2.124

(4) For an unpaired comparison, calculate the t-value:

$$t_{\text{unpaired}} = (I_{\text{avg}} - R_{\text{avg}}) / ((I_{\text{sd}}^2 + R_{\text{sd}}^2) / n)^{1/2}$$

(5) For a paired comparison, calculate the “n-1” standard deviation (squared) of the differences,  $d_i$ , between the paired results, where “i” represents the  $i^{\text{th}}$  test of n number of tests:

$$S_D^2 = (Sd_i^2 - ((Sd_i)^2/n))/(n-1)$$

(6) For a paired comparison, calculate the t-value:

$$t_{\text{paired}} = (I_{\text{avg}} - R_{\text{avg}}) / (S_D^2/n)^{1/2}$$

(b) The absolute value of t must be less than the critical t value,  $t_{\text{crit}}$  at a 95% confidence interval for “n-1” degrees of freedom. The following table lists 95% confidence interval  $t_{\text{crit}}$  values for n-1 degrees of freedom:

n-1	$t_{\text{crit}}$
6	2.45
7	2.36
8	2.31
9	2.26
10	2.23
11	2.20
12	2.18
13	2.16
14	2.14
15	2.13
16	2.12
17	2.11
18	2.10
19	2.09
20	2.09

(b) Measurement systems that conform to the provisions of §§ 1065.915 through 1065.953 are considered to be in compliance with the accuracy and precision requirements of paragraph (a) of this section.

~~(a) Measurement systems used for in-use testing must be accurate to within ±5 percent compared to engine dynamometer testing conducted according to the test procedures of this part that are applicable for your engine. These systems must also have a precision of ±5 percent or better. Determine accuracy and precision of an in-use system by simultaneously measuring emissions using the engine dynamometer test procedures of this part and the in-use system. To have a statistically valid sample, measure emissions during at least 3 tests each for at least 3 different engines. You must conduct these verification tests using the test cycle specified in the standard setting part, unless we approve a different test cycle.~~

~~(1) A system must meet the following conditions to be considered sufficiently accurate:~~

~~(i) The correlation coefficient (r) for a least-squares linear fit that includes the origin must be 0.95 or higher.~~

~~(ii) The average ratio (for all tests) of the emission rate from the in-use system divided by the emission rate from the dynamometer procedure must be 0.97 to 1.05.~~

~~(2) For a system to be considered sufficiently precise, the average coefficient of variance for all engines must be 5 percent or less for each pollutant.~~

~~**Note:** Increasing the length of the sampling period may be an effective way to improve precision.~~

~~(b) Measurement systems that conform to the provisions of §§ 1065.915 through 1065.950 are considered to be in compliance with the accuracy and precision requirements of paragraph (a) of this section.~~

#### **§ 1065.915 Equipment specifications for SI engines.**

This section describes equipment you may use to measure in-use emissions [from SI engines](#).

You may use other equipment and measurement systems that conform to the requirements of §§ 1065.905 and 1065.910.

(a) The primary components of the in use measurement system are a mass air flow sensor, a portable FID, a zirconia-based NOX sensor, a zirconia-based air/fuel ratio sensor, and a portable NDIR analyzer.

(1) The mass air flow sensor must meet the requirements of § 1065.930.

(2) The portable FID must meet the requirements of § 1065.935.

(3) The NOX and air/fuel sensors must meet the requirements of § 1065.940

(4) The NDIR analyzer must meet the requirements of § 1065.945.

(b) You must measure the following parameters continuously at a rate of 3 Hz or higher and store the data electronically:

(1) THC, NOX, CO concentrations.

(2) Mass air-fuel ratio.

(3) Intake air flow rate.

(4) Engine speed.

(5) Parameters used to calculate torque.

(c) You must minimize sample line length for any analyzers that require a physical sample be drawn from the exhaust to the analyzer (*i.e.*, THC and CO analyzers). You must draw these samples at a constant flow rate. In no case may you use any combination of sample line length and sample flow rate that would require more than 10 seconds for the analyzer to reach 90 percent of its final response after a step change to the input concentration at the opening of the sample probe. For residence time delays between 1 and 10 seconds, you must correct the measurements to be consistent with the data for engine speed, torque, and air intake. You may also correct other measurements with less than delays less than 1 second.

(d) You may insert the sample probes and sensors into the exhaust pipe, or mount them in an exhaust extension that is connected to the exhaust pipe with negligible leaking. Place the sample probes and sensors close enough to the center line of the exhaust pipe to minimize boundary layer effects from the wall.

#### [§1065.917 Equipment specifications for CI engines](#)

[This section describes equipment you may use for field testing emissions from CI engines. You may use other equipment and measurement systems that conform to the measurement accuracy and precision requirements of §§1065.905 and 1065.910.](#)

[\(a\) The primary components of the in-use measurement system are a gaseous flow sensor, a portable HC analyzer, a portable NOx analyzer, a portable CO/CO2 analyzer, and a portable PM analyzer.](#)

[\(b\) You must measure and/or calculate the following parameters and store the data electronically:](#)

[\(1\) THC \(or NMHC\), NOx, CO, and CO2 concentrations continuously at a rate of at least 1 Hz](#)

[\(2\) Integrated particulate matter mass at a rate of at least 0.001 Hz \(~once every 16.5 minutes\) or particulate matter mass concentration at a rate of at least 1 Hz.](#)

[\(3\) A value linearly proportional to standard volumetric exhaust flow rate continuously at a rate of at least 1 Hz.](#)

[\(4\) For engines equipped with one or more aftertreatment devices that reduce NOX or NMHC emissions, measure exhaust gas temperature within 12 inches of the outlet of the aftertreatment device.](#)

[\(5\) Ambient temperature continuously at a rate of at least 0.001 Hz \(~once every 16.5 minutes\)](#)

[\(6\) Barometric pressure continuously at a rate of at least 0.001 Hz \(~once every 16.5 minutes\)](#)

(c) You may make other measurements of vehicle, exhaust, or ambient parameters.

(d) You must minimize sample line length for any analyzers that require a physical sample be drawn from the exhaust to the analyzer. In no case may you use any combination of sample line length and sample flow rate that would require more than 10 seconds for the analyzer to reach 90 percent of its final response after a step change to the input concentration at the opening of the sample probe. You must correct the time alignment and dispersion of measurements to be consistent with the other collected data. Refer to Society of Automotive Engineers Technical Paper, 2001-01-3536, "Relationships Between Instantaneous and Measured Emissions in Heavy Duty Applications", Ganesan B. and Clark N. N., West Virginia University for an appropriate technique to correct for these effects.

(e) You may insert the sample probes and sensors into the exhaust pipe, or mount them in an exhaust extension that is connected to the exhaust pipe provided that there is negligible leaking. Place the probes far enough into the exhaust pipe or extension so as to prevent dilution of sample via exhaust mixing with ambient air. Place the sample probes and sensors close enough to the center line of the exhaust pipe to minimize boundary layer effects from the wall.

#### **§ 1065.920 Equipment setup and test run ~~for SI engines~~.**

This section describes how to set up the equipment specified in § 1065.915, and how to use it to measure in-use emissions from SI engines.

(a) Inspect the vehicle or equipment to determine whether it meets any applicable requirements of the standard setting part. This may include requirements related to model year, accumulated hours of operation, fuel specifications, maintenance history, engine temperatures, etc.

(b) Perform calibrations as specified in this subpart. In the field, this generally will require only zeroing and spanning the instruments. However, each instrument must have been fully calibrated according to the instrument manufacturer's specifications. Nonlinear calibrations generated previously from the full calibration may be used after zeroing and spanning the instruments. Spanning can be performed using a single gas bottle, consistent with good engineering practice, and provided that stability of the span mixture has been demonstrated.

(c) Connect the data recorder (with any necessary signal interpreters or converters) to the engine's electronic control module.

(d) Disconnect the air intake system, as necessary, to attach the mass air flow sensor. Reconnect the system after attaching the mass air flow sensor.

(e) Attach the sample extension to the exhaust outlet.

(f) Turn on instruments and allow them to warm up as necessary.

(g) Begin sampling. You do not need to begin recording the data at this point.

(h) Begin operating the vehicle or equipment in a normal manner.

**Note:** We may require you to operate the vehicle or equipment in a specific manner.

(i) Begin recording engine speed, engine torque (or surrogate), intake air flow, emissions data (THC, NOX, CO, air/fuel ratio), and time. This time marks the beginning of the sampling period.

(j) Continue recording data and operating the vehicle or equipment in a normal manner until the end of the sampling period. The length of the sampling period is based on good engineering practice, the precision requirements of § 1065.910, and applicable limits in the standard-setting part.

(k) You may measure background concentrations and correct measured emission values accordingly. However, if any background corrections are equivalent to 5 percent or more of the maximum emissions allowed by the applicable standard, the test shall be voided and repeated in an environment with lower background concentrations.

#### **§ 1065.925 SI Calculations.**

(a) [Reserved]

(b) Convert emission analyzer data to instantaneous concentrations in ppm (ppmC for the FID).

(c) Calculate instantaneous exhaust volumetric flow rates in standard m<sup>3</sup>/hr (volume and density values used in these calculations are corrected to standard conditions of 20 °C and 101.3kPa.). Calculate exhaust volumetric flow rate from the following equation:

Exhaust volumetric flow rate = (intake air mass flow rate)(1+mass fuel/air ratio)/(density of exhaust)

(1) If you do not know the instantaneous density of the exhaust, use the minimum density of the exhaust that occurs over the course of the test, corrected to standard conditions.

- (2) For gasoline-fueled engines designed to be operated at stoichiometric fuel/air ratios, you may assume that the density of the exhaust is 1202 g/m<sup>3</sup> at standard conditions of 20 °C and 101.3 kPa.
- (3) For LPG-fueled engines designed to be operated at stoichiometric fuel/air ratios, you may assume that the density of the exhaust is 1175 g/m<sup>3</sup> at standard conditions of 20 °C and 101.3 kPa.
- (4) For CNG-fueled engines designed to be operated at stoichiometric fuel/air ratios, you may assume that the density of the exhaust is 1149 g/m<sup>3</sup> at standard conditions of 20 °C and 101.3 kPa.
- (d) Calculate instantaneous emission rates (g/hr) using the following general equation:  
 Emission rate = (exhaust volumetric flow rate)(ppm)(density factor)/10<sup>6</sup>  
 Where:  
 Density factors are 576.8 g/m<sup>3</sup> for THC, 1913 g/m<sup>3</sup> for NOX, 1164 g/m<sup>3</sup> for CO.
- (e) Integrate instantaneous emission rates for the entire specified sample period.
- (f) Determine instantaneous brake torque and speed.
- (g) Calculate instantaneous brake power.
- (h) Integrate instantaneous brake power for the entire specified sample period.
- (i) Divide the integrated emission rates by the integrated brake power.
- These are your final brake-specific emission rates.

### § 1065.925 CI Calculations.

The nature of this data reduction scheme requires post-processing, real-time data reduction is not possible because the parameter of total work over the sampling period is used to determine the moving average interval.

(a) Convert data to engineering units at a standard condition. EPA recommends 293.15K and 101.325 kPa. For these calculations all exhaust constituents except particulate matter mass may be considered ideal gases with a universal gas constant Ru of 8.31434 kJ/kg-K. At the EPA recommended standard conditions of 293.15K and 101.325 kPa, one mole of ideal gas will occupy 24.0548 standard liters of volume (0.849487 standard cubic feet of volume). Other standard conditions may be used if used consistently.

(b) Calculate a value proportional to the total work performed over the sampling period by summing the 1Hz data:

$$TotalWorkFactor = \left[ \frac{g_{fuel}}{molCO_2} \times \frac{1}{BSFC} \right] \times \sum_0^{Total} CO_2 x Flow$$

Where,

$$\begin{aligned} \frac{g_{fuel}}{molCO_2} &= \text{grams of fuel per mole of CO}_2 \\ &= (H:Cratio_{fuel} * 1 \text{ mol H} * MWH + 1 \text{ mol C} * MWC) / 1 \text{ mol CO}_2 \\ &= H:Cratio_{fuel} * MWH + MWC \\ &= H:Cratio_{fuel} * 1.008 + 12.011 \\ &= 1.850 * 1.008 + 12.011 \\ &= 13.876 \text{ (for the nominal H:Cratio of 1.850 for \#2 diesel fuel)} \end{aligned}$$

H:Cratio<sub>fuel</sub>=atomic hydrogen-to-carbon ratio of fuel.

This may be a measured value based on a fuel analysis of the in-use fuel or a nominal value of 1.850 for #2 diesel may be used.

MWC=molecular weight of carbon=12.011 g/mol

MWH=molecular weight of atomic hydrogen=1.008 g/mol

BSFC = brake-specific fuel consumption in grams of fuel per brake horsepower-hour (g<sub>fuel</sub>/bhp-hr). This value is the average BSFC reported certification value for the engine family being field-tested. The average BSFC is the arithmetic mean of the transient test BSFC and the steady-state test BSFC (weighted

as per emissions' mode weightings). If the engine family is only required to be certified to one certification test, then the BSFC of that test will be BSFC used for this calculation.

Flow = signal linearly proportional to exhaust volume flow at standard conditions = volume/time  
No engineering units are necessary for this value because the same signal is used in later calculations,  
which fortuitously happens to cancel out these unspecified units.

CO2 = mole fraction of CO2=volume fraction of CO2=%CO2/100

The formula to calculate "gfuel/molCO2" assumes complete combustion of the fuel's carbon to carbon dioxide. If this assumption is not appropriate for a given engine family, the Administrator may approve in advance an application to use an alternative formula that accounts for incomplete combustion of the fuel's carbon. Also O2 and other gases may be used to calculate the percent CO2, provided that the technique meets the accuracy and precision requirements stated previously.

(c)Calculate XX% and X.X% of this Total Work Factor. Respectively these are the summing interval, Si, and the increment interval, Ii, for a constant-work moving average:

(1) Si = Total Work Factor \* 0.XX

(2) Ii = Total Work Factor \* 0.0XX

(d)Explanation of a constant-work moving average. The first value summed in this moving average is the first data record and the summing continues until the sum of the work is equal to or greater than Si. The number of records that result in this sum is the interval over which average brake-specific emissions are determined. The average brake-specific emissions over this first interval is the first result of the test. Si is then reset to zero, and the first record of the second moving average is the first record after the work increment Ii. The number of records summed in the increment is determined by summing work from the first data record until the work sum becomes greater than or equal to Ii. The moving average progresses by averaging emissions over a XX% work interval; moving the starting point for the next average by an increment of X.X% work; repeating the emissions averaging over that interval, and then repeating this progression until the work sum can not achieve a value greater than or equal to Si. This last remaining incomplete sum is discarded, and the progression of the moving average is terminated. The specified XX% interval, Si and X.X% increment, Ii result in about XX to XX individual results for any given sample period, regardless of the total sample time. Because time-rates of work are not typically constant, and because the raw data is collected at a discrete time-rate (i.e. 1Hz), intervals of constant work will occur over varying lengths of time.

(e)Calculate the results of the constant-work moving averages by summing the total mass of each pollutant over each constant work interval and dividing by the work performed over each interval.:

$$BrakeSpecificNOx = \frac{MWNO2 \times \sum_0^{Si} NOx \times Flow}{\left[ \frac{gfuel}{molCO2} \times \frac{1}{BSFC} \right] \times \sum_0^{Si} CO2 \times Flow}$$

Where,

MWNO2=molecular weight of NO2=46.006 g/mol

NOx=volume fraction of NOx=molar fraction of Nox=NOx in parts per million, ppm / 1,000,000  
and the other variables have been defined above.

$$BrakeSpecificCO = \frac{MWCO \times \sum_0^{Si} CO \times Flow}{\left[ \frac{g_{fuel}}{molCO_2} \times \frac{1}{BSFC} \right] \times \sum_0^{Si} CO_2 \times Flow}$$

Where,

MWCO=molecular weight of CO=28.011 g/mol

CO=volume fraction of CO=molar fraction of CO=CO in parts per million, ppm / 1,000,000

$$BrakeSpecificTHC = \frac{MWHC \times \sum_0^{Si} THC \times Flow}{\left[ \frac{g_{fuel}}{molCO_2} \times \frac{1}{BSFC} \right] \times \sum_0^{Si} CO_2 \times Flow}$$

Where,

MWHC=molecular weight of THC=(MWC+MWH\*HCratiofuel)=13.876 g/mol\*

\*This value assumes an Hcratiofuel value of 1.85. For this calculation 1.85 should be used under all circumstances unless an application for an alternative value is approved in advance by the Administrator.

THC=molar fraction of THC=THC in parts per million carbon equivalent, ppm / 1,000,000

If PM mass concentration is measured on continuously at a rate of at least 1Hz, then the following equation may be used to calculate brake-specific PM emissions:

$$BrakeSpecificPM = \frac{\sum_0^{Si} PM \text{ concentration} \times Flow}{\left[ \frac{g_{fuel}}{molCO_2} \times \frac{1}{BSFC} \right] \times \sum_0^{Si} CO_2 \times Flow}$$

Where

Pmconcentration is the mass concentration of PM per unit standard volume of exhaust.

If PM mass is integrated via proportional partial flow sampling over fixed time intervals, the brake-specific PM emissions is calculated by dividing total PM mass of each interval by the total work performed over that same time interval. If the work summed over a PM time interval is less

than Si, the result shall be recorded, but not used in the evaluation of any average or peak PM emissions for comparison against the NTE limits.

**§ 1065.930 Specifications for SI mass air flow sensors.**

- (a) Measure the intake air flow using the engine's mass air flow sensor. If the engine is not equipped with a mass air flow sensor, you need to install one.
- (b) The sensor design must have an accuracy and precision of  $\pm 5$  percent under steady-state laboratory conditions.
- (c) The sensor must reach at least 90 percent of its final response within 0.3 seconds after any step change to the flow rate greater than or equal 80 percent of full scale.
- (d) Calibrate the sensor according to good engineering practice. Verify for each engine before testing that the sensor accurately reads the idle intake air flow rate based on measured manifold temperature (TM) and pressure PM). Use the following equation:

Intake air flow =(displacement)(rpm)(volumetric efficiency)(PM/101.3 kPa)(293.15 K/TM)

**§ 1065.933 Specifications for CI mass air flow sensors.**

- (a) Measure the intake air flow or exhaust flow using a sensor that meets the accuracy and precision specifications above.
- (b) Calibrate the sensor according to good engineering practice. Verify for each engine before testing that the sensor accurately returns a proportional increase in signal between the curb idle flow rate and a high idle flow rate, based on engine rpm, measured manifold absolute temperature,  $T_M$ , and absolute pressure,  $P_M$ . Use the following equation:

$$\frac{Flow_{hi}}{Flow_{lo}} = \frac{rpm_{hi} \times \eta_{vol-hi} \times P_{M-hi} \times T_{M-lo}}{rpm_{lo} \times \eta_{vol-lo} \times P_{M-lo} \times T_{M-hi}}$$

Where,

hi subscript refers to a variable value at the high idle condition

lo subscript refers to a variable value at the low idle condition

Flow=sensor signal

rpm=engine crankshaft rotational frequency

etavol=volumetric efficiency, volume displaced at PM and TM / engine displacement volume

PM=intake manifold absolute pressure

TM=intake manifold absolute temperature

(c) If exhaust flow is calculated from intake air flow, you may account for additional exhaust flow due to fuel combustion by assuming complete combustion and exhaust is an ideal gas, or you may use an independent fuel measurement.

**§ 1065.935 Specifications for THC analyzers.**

- (a) Use a flame ionization detector (FID).
- (b) The analyzer must have an accuracy and precision of  $\pm 2$  percent of point or better under steady-state laboratory conditions.
- (c) The analyzer must reach at least 90 percent of its final response within 1.0 second after any step change to the input concentration greater than or equal 80 percent of full scale.
- (d) Zero and span the analyzer daily during testing. Calibrate it according to the analyzer manufacturer's specifications.

**§ 1065.940 Specifications for NOX and air/fuel sensors.**

- (a) Use stabilized zirconia-based sensors.
- (b) The sensors must have an accuracy and precision of  $\pm 2$  percent of point or better under steady-state laboratory conditions.
- (c) The sensors must reach at least 90 percent of its final response within 1.0 second after any step change to the input concentration greater than or equal 80 percent of full scale.
- (d) The sensors must be zeroed and spanned daily during testing, and must be calibrated according to the sensor manufacturer's specifications.

**§ 1065.945 Specifications for CO analyzers.**

- (a) Use a non-dispersive infrared (NDIR) detector that is compensated for CO<sub>2</sub> and water interference.
- (b) The analyzer must have an accuracy and precision of  $\pm 2$  percent of point or better under steady-state laboratory conditions.
- (c) The analyzer must reach at least 90 percent of its final response within 5.0 second after any step change to the input concentration greater than or equal 80 percent of full scale.
- (d) The analyzer must be zeroed and spanned daily during testing, and must be calibrated according to the analyzer manufacturer's specifications.

**§ 1065.950 Specifications for speed and torque measurement.**

- (a) Determine torque from a previously determined relationship of torque and engine speed, throttle position, and/or manifold absolute pressure. Torque estimates must be between 85 percent and 105 percent of the true value. You can demonstrate compliance with this accuracy requirement using steady-state laboratory data.
- (b) Measure speed from the engine's electronic control module. Speed estimates must be within  $\pm 5$  rpm of the true value.

**§ 1065.955 Specifications for PM measurement.**

(a) Use a PM analyzer or sensor that meets the accuracy and precision specifications above (§ 1065.910, § 1065.917).

(b) The analyzer must be zeroed and spanned daily during testing, and must be calibrated according to the sensor manufacturer's specifications.

## **Subpart K—Definitions and Other Reference Information**

### **§ 1065.1001 Definitions.**

The following definitions apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives to them. The definitions follow:

*Accuracy* means the maximum difference between a measured or calculated value and the true value, where the true value is determined by NIST.

*Act* means the Clean Air Act, as amended, 42 U.S.C. 7401 *et seq.*

*Adjustable parameter* means any device, system, or element of design that someone can adjust (including those which are difficult to access) and that, if adjusted, may affect emissions or engine performance during emission testing or normal in-use operation.

*Aftertreatment* means relating to any system, component, or technology mounted downstream of the exhaust valve or exhaust port whose design function is to reduce exhaust emissions.

*Auxiliary emission-control device* means any element of design that senses temperature, engine speed, motive speed, transmission gear, atmospheric pressure, manifold pressure or vacuum, or any other parameter to activate, modulate, delay, or deactivate the operation of any part of the emission control system. This also includes any other feature that causes in-use emissions to be higher than those measured under test conditions, except as we allow under this part.

*Brake power* has the meaning given in the standard-setting part. If it is not defined in the standard-setting part, brake power means the usable power output of the engine not including power required to operate fuel pumps, oil pumps, or coolant pumps.

*Calibration* means the set of specifications and tolerances specific to a particular design, version, or application of a component or assembly capable of functionally describing its operation over its working range.

*Certification* means obtaining a certificate of conformity for an engine family that complies with the emission standards and requirements in this part.

*Compression-ignition* means relating to a type of reciprocating, internal combustion engine that is not a spark ignition engine.

*Constant-speed engine* means an engine governed to operate only at its rated speed.

*Designated Officer* means the Manager, Engine Programs Group (6405–J), U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., Washington, DC 20460.

*Emission-control system* means any device, system, or element of design that controls or reduces the regulated emissions from an engine.

*Emission-data engine* means an engine that is tested for certification.

*Emission-related maintenance* means maintenance that substantially affects emissions or is likely to substantially affect emissions deterioration.

*Engine* means an engine to which this part applies.

*Engine-based* means having emission standards related to measurements using an engine dynamometer, in units of grams of pollutant per kilowatt-hour.

*Engine family* means a group of engines with similar emission characteristics, as specified in the standard-setting part.

*Equipment-based or vehicle-based* means relating to programs that require that a piece of equipment of vehicle be certified, rather than only the engine.

*Fuel system* means all components involved in transporting, metering, and mixing the fuel from the fuel tank to the combustion chamber(s), including the fuel tank, fuel tank cap, fuel pump, fuel filters, fuel lines, carburetor or fuel injection components, and all fuel system vents.

*Fuel type* means a general category of fuels such as gasoline or LPG. There can be multiple grades within a single type of fuel, such as summer-grade gasoline and winter-grade gasoline.

*Good engineering judgment* has the meaning we give it in § 1068.5 of this chapter.

*Identification number* means a unique specification (for example, model number/serial number combination) that allows someone to distinguish a particular engine from other similar engines.

*Idle speed* means the lowest engine speed with zero load.

**Note:** Warm idle speed is the idle speed of a warmed-up engine.

*Manufacturer* has the meaning given in section 216(1) of the Act. In general, this term includes any person who manufactures an engine for sale in the United States or otherwise introduces a new engine into commerce in the

United States. This includes importers that import engines for resale.

*Maximum test torque* means: (1) For throttled engines, the torque output observed at wide-open throttle at a given speed. (2) For non-throttled engines, the torque output observed with the maximum fueling rate possible at a given speed.

*Nonmethane hydrocarbons* means the sum of all hydrocarbon species measured by a FID except methane, expressed with an assumed mass 13.876 grams per mole of carbon atoms.

*Nonroad* means relating to nonroad engines.

*Nonroad engine* has the meaning given in § 89.2 of this chapter. In general this means all internal combustion engines except motor vehicle engines, stationary engines, or engines used solely for competition.

*Oxides of nitrogen* means compounds containing only nitrogen and oxygen.

Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO<sub>2</sub> (assume a molecular weight for all oxides of nitrogen equivalent to that of NO<sub>2</sub>). This correction is included in the equations specified for calculating NOX emissions.

*Oxygenated fuel* means a fuel that is comprised of oxygen-containing compound, such as ethanol or methanol. Generally, testing engines that use oxygenated fuels requires the use of the sampling methods in subpart I of this part. However, you should read the standard-setting part and subpart I of this part to determine which sampling methods to use.

*Precision* means two times the coefficient of variance of multiple measurements, except where specified otherwise.

*Revoking a certificate of conformity* means discontinuing the certificate for an engine family. If we revoke a certificate, you must apply for a new certificate before continuing to introduce into commerce the affected engines. This does not apply to engines you no longer possess.

*Scheduled maintenance* means maintenance (*i.e.*, adjusting, repairing, removing, disassembling, cleaning, or replacing components or systems) that is periodically needed to keep a part from failing or malfunctioning. It also may mean actions you expect are necessary to correct an overt indication of failure or malfunction for which periodic maintenance is not appropriate.

*Span* means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 and 100 percent of the maximum value in the instrument range (*e.g.* a span gas).

*Spark-ignition* means relating to a gasoline-fueled engine or other engines with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle.

Spark-ignition engines usually use a throttle to regulate intake air flow to control power during normal operation.

*Standard-setting part* means the part in the Code of Federal Regulations that defines emission standards for a particular engine (see § 1065.1(a)).

*Stoichiometry* means the proportion of a mixture of air and fuel such that the fuel is fully oxidized with no remaining oxygen. For example, stoichiometric combustion in gasoline engines typically occurs at an air-fuel mass ratio of about 14.7.

*Suspending a certificate of conformity* means temporarily discontinuing the certificate for an engine family. If we suspend a certificate, you may not sell engines from that engine family unless we reinstate the certificate or approve a new one.

*Test engine* means an engine in a test sample.

*Test sample* means the collection of engines selected from the population of an engine family for emission testing.

*Total Hydrocarbon (THC)* means the sum of all hydrocarbon species measured by an FID, expressed with an assumed mass 13.876 grams per mole of carbon atoms.

*Total Hydrocarbon Equivalent* means the sum of the carbon mass contributions of non-oxygenated hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as petroleum fueled engine hydrocarbons. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

*United States* means the States, the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, Guam, American Samoa, the U.S. Virgin Islands, and the Trust Territory of the Pacific Islands.

*Wide-open throttle* means maximum throttle opening for throttled engines. Unless this is specified at a given speed, it refers to maximum throttle opening at maximum speed. For electronically controlled or other engines with multiple possible fueling rates, wide open throttle also means the maximum fueling rate at maximum throttle opening under test conditions.

*Zero* means to adjust an instrument so that it gives a proper response to a blank calibration standard (e.g. zero-grade air).

#### **§ 1065.1005 Symbols, acronyms, and abbreviations.**

The following symbols, acronyms, and abbreviations apply to this part:

°degrees.

" inches.

ASTM American Society for Testing and Materials.

C Celsius.

cc cubic centimeters.

CFR Code of Federal Regulations.

CFV critical-flow venturi.

CI compression-ignition.

CLD chemiluminescent detector.

CO carbon monoxide.

CO<sub>2</sub> carbon dioxide.

CVS constant-volume sampler.

DF deterioration factor.

F Fahrenheit.

EFC electronic flow control.

EPA Environmental Protection Agency.

ft feet.

FID flame ionization detector.

g/kW-hr grams per kilowatt-hour.

g/liter grams per liter.

g/m<sup>3</sup> grams per cubic meter.

Hz hertz.

IBP initial boiling point.

ISO International Organization for Standardization.

kPa kilopascal.

lbs. pounds.

LPG liquefied petroleum gas.

m meters.

ml milliliters.

mm Hg millimeters of mercury.

NDIR nondispersive infrared.

NIST National Institute for Standards and Testing.

NMHC nonmethane hydrocarbons.

NMHCE nonmethane hydrocarbon equivalent.

NO nitric oxide.

NO<sub>2</sub> nitrogen dioxide.

NO<sub>x</sub> oxides of nitrogen (NO and NO<sub>2</sub>).

O<sub>2</sub> oxygen.

PDP positive-displacement pump.  
 ppm parts per million.  
 ppmC parts per million carbon.  
 RMS root-mean square.  
 rpm revolutions per minute.  
 sec seconds.  
 SI spark-ignition.  
 THC total hydrocarbon.  
 THCE total hydrocarbon equivalent.  
 U.S.C. United States Code.

#### § 1065.1010 Reference materials.

We have incorporated by reference the documents listed in this section. The Director of the Federal Register approved the incorporation by reference as prescribed in 5 U.S.C. 552(a) and 1 CFR part 51. Anyone may inspect copies at the U.S. EPA, Air and Radiation Docket and Information Center, 1301 Constitution Ave., NW. Room B102, EPA West Building, Washington, DC 20460 or the Office of the Federal Register, 800 N. Capitol St., NW. 7<sup>th</sup> Floor, Suite 700, Washington, DC.

(a) *ASTM material.* Table 1 of § 1065.1010 lists material from the American Society for Testing and Materials that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may purchase copies of these materials from the American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428. Table 1 follows:

TABLE 1 OF § 1065.1010.—ASTM MATERIALS

Document number and name	Part 1065 reference
ASTM D 86–01, Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure .....	1065.210
ASTM D 323–99a, Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method) .....	1065.210
ASTM D 1266–98, Standard Test Method for Sulfur in Petroleum Products (Lamp Method) .....	1065.210
ASTM D 1319–02, Standard Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption .....	1065.210
ASTM D 1267–02, Standard Test Method for Gage Vapor Pressure of Liquefied Petroleum (LP) Gases (LP-Gas Method) .....	1065.220
ASTM D 1837–02, Standard Test Method for Volatility of Liquefied Petroleum (LP) Gases .....	1065.220
ASTM D 1838–91 (Reapproved 2001), Standard Test Method for Copper Strip Corrosion by Liquefied Petroleum (LP) Gases ....	1065.220
ASTM D 1945–96 (Reapproved 2001), Standard Test Method for Analysis of Natural Gas by Gas Chromatography .....	1065.215
ASTM D 2158–02, Standard Test Method for Residues in Liquefied Petroleum (LP) Gases .....	1065.220
ASTM D 2163–91 (Reapproved 1996), Standard Test Method for Analysis of Liquefied Petroleum (LP) Gases and Propene Concentrates by Gas Chromatography .....	1065.220
ASTM D 2598–02, Standard Practice for Calculation of Certain Physical Properties of Liquefied Petroleum (LP) Gases from Compositional Analysis .....	1065.220
ASTM D 2713–91 (Reapproved 2001), Standard Test Method for Dryness of Propane (Valve Freeze Method) .....	1065.220
ASTM D 2784–98, Standard Test Method for Sulfur in Liquefied Petroleum Gases (Oxy-Hydrogen Burner or Lamp) .....	1065.220
ASTM D 3231–02, Standard Test Method for Phosphorus in Gasoline .....	1065.210
ASTM D 3237–97, Standard Test Method for Lead in Gasoline By Atomic Absorption Spectroscopy .....	1065.210

[ASTM F 1471–93, 1065.115](#)

[ASTM D2986-95a, 1065.115](#)

(b) *ISO material.* Table 2 of § 1065.1010 lists material from the International Organization for Standardization that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the section of this part where we reference it. Anyone may purchase copies of these materials from the International Organization for Standardization, Case Postale 56, CH–1211 Geneva 20, Switzerland. Table 2 follows:

TABLE 2 OF § 1065.1010.—ISO MATERIALS

Document number and name	Part 1065 reference
ISO 8178-1, Reciprocating internal combustion engines—Exhaust emission measurement—Part 1: Test-bed measurement of gaseous and particulate exhaust emissions, 1996.	1065.130, 1065.135, 1065.140, 1065.155.

[ISO 14644-1 1065.160](#)

**§ 1065.1015 Confidential information.**

(a) Clearly show what you consider confidential by marking, circling, bracketing, stamping, or some other method. We will store your confidential information as described in 40 CFR part 2. Also, we will disclose it only as specified in 40 CFR part 2.

(b) If you send us a second copy without the confidential information, we will assume it contains nothing confidential whenever we need to release information from it.

(c) If you send us information without claiming it is confidential, we may make it available to the public without further notice to you, as described in § 2.204 of this chapter.